The CRUSHED STONE JOURNAL

In This Issue

Stone Screenings for Stabilized Base Construction

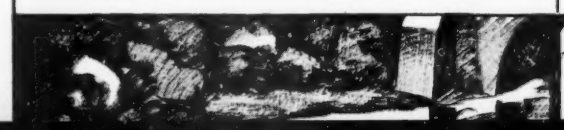
Study and Statement of Quality of a Road Surface

Management's New Responsibilities

Eli Whitney Blake and the World's First Stone-Crusher

September-October · 1938

Official Publication
NATIONAL CRUSHED STONE ASSOCIATION



Technical Publications

of the

National Crushed Stone Association, Inc.

◈

BULLETIN No. 1

The Bulking of Sand and Its Effect on Concrete

BULLETIN No. 2

Low Cost Improvement of Earth Roads with Crushed Stone

BULLETIN No. 3

The Water-Ratio Specification for Concrete and Its Limitations

BULLETIN No. 4

"Retreading" Our Highways

BULLETIN No. 5

Reprint of "Comparative Tests of Crushed Stone and Gravel Concrete in New Jersey" with Discussion

BULLETIN No. 6

The Bituminous Macadam Pavement

BULLETIN No. 7

Investigations in the Proportioning of Concrete for Highways

BULLETIN No. 8

The Effect of Transportation Methods and Costs on the Crushed Stone, Sand and Gravel, and Slag Industries

BULLETIN No. 9

Tests for the Traffic Durability of Bituminous Pavements

BULLETIN No. 10

Stone Sand

Single copies of the above bulletins are available upon request.

Manual of Uniform Cost Accounting Principles and Procedure for the Crushed Stone Industry ($2.00 per copy)

The Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

J. R. BOYD, Editor

NATIONAL CRUSHED STONE ASSOCIATION

1735 14th St., N. W.
Washington D. C.

OFFICERS

T. I. WESTON, President
WM. E. HILLIARD, Treasurer
J. R. BOYD, Administrative Director
A. T. GOLDBECK, Engineering Director

REGIONAL VICE PRESIDENTS

C. M. DOOLITTLE — W. T. RAGLAND
E. EIKEL — J. A. RIGG
N. E. KELB — A. J. WILSON
PORTER W. YETT

EXECUTIVE COMMITTEE

T. I. WESTON, Chairman
OTHO M. GRAVES — H. E. RODES
N. E. KELB — STIRLING TOMKINS
E. J. KRAUSE — T. I. WESTON
RUSSELL RAREY — A. L. WORTHEN

Contents

Page

Stone Screenings for Stabilized Base Construction
—By A. T. Goldbeck - - - 3

Study and Standard of Quality of a Road Surface
—By R. H. Baldock - - - 11

Management's New Responsibilities
—By William L. Batt - - - 25

Eli Whitney Blake and the World's First Stone-Crusher
—By Richard S. Kirby and Joseph W. Roe - - - 27

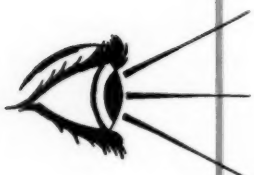
"Out of Sight Out of Mind"

HISTORY records the unfortunate demise of many a product which has come to an untimely end for lack of receiving publicity. At one time they rode the crest of the wave of popular approval. Where are they today? Failure to recognize the fundamental importance of repeat advertising spelled their doom.

Manufacturers of machinery and equipment used in the production of crushed stone have for years recognized the exceptional opportunity afforded by the Manufacturers' Division Exposition for keeping their products in the sight and in the minds of the leading crushed stone producers of the country.

This exposition will again be staged in conjunction with the Twenty-Second Annual Convention of the National Crushed Stone Association and manufacturers desiring to utilize this proven medium for stimulating sales to crushed stone producers are cordially invited to participate. Full details can be obtained upon request to the

NATIONAL CRUSHED STONE ASSOCIATION
1735 Fourteenth Street, N. W.
WASHINGTON, D. C.



Manufacturers' Division Exposition
in conjunction with
The 22nd Annual Convention
of the
NATIONAL CRUSHED STONE ASSOCIATION
Netherland Plaza Hotel, Cincinnati, Ohio
JANUARY 30, 31 AND FEBRUARY 1, 1939

THE
CRUSHED STONE JOURNAL
WASHINGTON, D. C.
Vol. XIII No. 5 SEPTEMBER-OCTOBER, 1938

Stone Screenings for Stabilized Base Construction

By A. T. GOLDBECK
Engineering Director,
National Crushed Stone Association

◆ **Stone screenings is an available and valuable material for stabilized base construction. Whether it should be used as an agent for stabilizing soils, what its gradation should be for the best results, and how it acts with different kinds of admixtures are the questions which can be best answered by laboratory research, followed by field investigations. The purpose of the investigations described in the following article was to determine that combination of gradation of screenings and of admixtures which would give the most satisfactory results. The conclusions reached should constitute a valuable contribution to the knowledge in this important field.**

THE term "stabilized soil" is one which has sprung into great prominence in the highway engineering profession during the last several years. This term connotes the treatment of natural soil in some way so as to render it resistant to loads at all seasons of the year.

It has been known for many years that clay soils may be improved in their bearing value by the admixture of sand and, further, that loose, clean sand may be stabilized by admixtures of small amounts of clay. The sand is stable provided it is bound together with just enough clay to serve as a binding medium, but not so much as to cause separation of the sand grains. The old sand-clay roads and the top-soil roads of the South are notable examples of stabilized soil.

Comparatively recently a number of different investigators have been adding admixture to these stabilized roads in an effort to further improve them. Some of these admixtures, such as calcium chloride, are intended to preserve a more favorable water content. Sodium chloride is intended to perform in the same manner and in part also to serve to increase the binding properties.

Bituminous materials, such as asphaltic emulsions, cut-back asphalts and tars have also been added in small amounts, primarily as waterproofing materials, and Portand cement has lately been used as a binder. These stabilized layers are intended as low cost bases and not primarily as wearing surfaces. Accordingly, they must be protected by a bituminous wearing surface of some variety.

Stone screenings, most emphatically, is an available and valuable material for stabilized base construction. Whether it should be used as an agent for stabilizing soils, what its gradation should be for the best results and how it acts with different kinds of admixtures, are questions which can best be answered by laboratory research, followed by field investigations in the form of experimental test roads. The purpose of the present investigations was to determine that combination of gradation of screenings and of admixtures which would give the most satisfactory results.

It is our conception that a stabilized screenings base for highways should possess the following characteristics:

1. It should transmit superimposed wheel loads to the sub-base without appreciable movement and with very little permanent deformation.
2. It should be able to perform these vital functions under all conditions of weather and moisture.
3. In the event of partial failure under unfavorable sub-grade conditions, it would seem desirable for the best results that stabilized screenings should have properties which would permit it to heal

or reknit itself together again. This point may be controversial.

4. It should remain stable, even after evaporation of capillary moisture has been prevented by the application of a bituminous wearing surface.

Logic would lead one to the conclusion that the maximum stability under wet conditions would be obtained, first, by using particles so graded in size that they will closely interlock one with the other and will provide a mixture having the greatest possible density and the smallest amount of porosity or percentage of voids; second, by the provision of just enough fine cementing material of some nature to aid in sticking the coarser particles together; third, by either integrally waterproofing the layer so as to exclude excessive quantities of water or by so controlling the amount of water that excessive film thickness of water will not be built up.

Engineers for many centuries have been familiar with the fact that the gradation of aggregate plays an important part in controlling density. Technicians of the old Roman Empire understood this matter, although perhaps somewhat imperfectly, and in more modern times, Feret of France and Fuller and Thompson of the United States made extensive studies of it in connection with Portland cement concrete. Dr. C. M. Strahan of the University of Georgia studied gradation in connection with his investigations of sand-clay roads and the gradations which he finally announced as being desirable agree remarkably well with those determined by Wm. B. Fuller in his studies of gradation of aggregate for maximum density of Portland cement concrete. It seemed desirable to take advantage of the work of these previous experimenters and Fuller's curve of maximum density and Strahan's gradations furnished an excellent starting point for our tests. Our preliminary investigations pointed strongly to the excellence of gradations corresponding to Fuller's curve. Talbot and Richart of Illinois, in connection with their formulation of the so-called "mortar-voids" theory for proportioning concrete had developed a method for determining the water content which would create maximum density in a mass of granular materials. A stabilized mixture is not unlike concrete and, accordingly, the work of Talbot and Richart was utilized. It was found that a water content which produced maximum density in the mix by Talbot and Richart's method also gave a mixture that could be easily placed and which would not shrink excessively.

Preliminary studies were also made to determine the amount of bituminous materials to use. This was done by trial, making use of different percentages of bituminous material, forming 1 inch by 1 inch cylindrical specimens under pressure and determining that percentage of bitumen which seemed necessary to prevent excessive absorption of water.

We are fortunate in having in our laboratory the circular track which we installed in 1931 and which we have since found useful for a great many different kinds of investigations. Let it be recalled that our track testing device consists essentially of a pneumatic tired wheel supporting a weight of 1900 pounds and attached to the end of a radial arm so that it may be rolled in a given track having a mean diameter of 14 feet. The test sections are laid on a concrete base having a trough shaped cross-section with curbs 6 inches in depth.

In the present investigation a plastic clay subgrade was first rolled in place on the concrete base and the test sections were then laid on this clay subgrade. Thus, a close approach to actual road conditions was obtained. The clay subgrade used was made from clay suitable for brick making and had a plastic index value of six.

Series I

Because of the low cost of stabilized roads screenings must be used with practically no change in gradation from that which it normally has. However, screenings from different sources vary rather widely in their gradations and, accordingly, it was decided to first determine whether these various gradations would have any appreciable effect on the efficiency of the resulting stabilized bases made with them. Three gradations were selected from our experience as representing the coarsest, intermediate and finest gradations which are apt to be normally produced. These gradations are given in Table I as follows:

TABLE I

GRADATION OF SCREENINGS

Sieve Size	Total Per cent Passing		
	Coarse	Medium	Fine
⅜ in.	100	100	100
No. 4	85	92	100
8	55	68	80
16	30	45	60
30	20	35	50
50	15	27	40
100	10	20	30
200	8	14	20

The screenings used was made from limestone which is supplied to the Washington market.

The first series of test sections included 8 different mixtures as follows:

TABLE II

STABILIZED SCREENINGS—FIRST CIRCULAR TRACK TEST

Section Number	Gradation	Per cent [a] Water	Per cent [a] MC-1 Cut-back
1	Coarse	9.6	..
2	Medium	10.4	..
3	Fine	11.7	..
4	Fine and clay [b]	12.0	..
8	Coarse	9.6	3.1
7	Medium	12.1	3.6
6	Fine	12.1	3.1
5	Fine and clay [b]	12.0	3.1

[a] Percentages are based on weight of aggregate.
[b] The fine gradation had 20 per cent passing the No. 200 sieve. For sections 4 and 8, 10 per cent of clay was substituted for 10 per cent of the limestone fines.

It will be noted that in Sections Nos. 4 and 8, both made with fine screenings, 10 per cent of clay was substituted for 10 per cent of the limestone dust passing the No. 200 sieve. The purpose of this was to determine if the clay imparted any beneficial properties to the screenings.

Test Procedure: A 3-inch layer of clay containing from 10 to 12 per cent of moisture was rolled to a compacted stable sub-base. The screenings for the various test sections previously graded to the right gradation were then mixed with water to the amounts shown in Table II and in cases of sections 5, 6, 7 and 8 medium curing cut-back asphalt complying with Asphalt Institute specification MC-1 was added and mixed with shovels until a thoroughly uniform mixture was obtained. After making each of these mixtures as described, they were placed on the damp rolled clay subgrade and then screeded and floated off in the same manner as would be practiced in finishing a concrete pavement.

The sections were then allowed to cure for a period of one week, the curing consisting of allowing the excess water to evaporate from the mixture. (Note: In two succeeding test tracks the curing time was increased to two weeks.) The surfaces were frequently rolled during this curing period in order to close up shrinkage cracks and to compact the mixtures. Finally, at the end of a week an asphaltic surface treatment was applied to all of the sections consisting of 0.25 gal. of RC-2 cut-back asphalt and 25 lb. of ½ inch stone chips per sq. yd.

After this surface treatment had cured for 2 weeks, 2000 passages of the loaded wheel, weaving over the entire surface, were made in order to thoroughly compact the surface treatment. The pavement was then considered ready for testing. It was quite evident, however, that section No. 5, made up with the fine gradation of screenings to which clay had been added in substitution for part of the limestone dust and containing the MC-1 cut-back asphalt, was quite unstable. It shoved so badly after the first 1000 passages of the loaded wheel weaving over the surface that it had to be removed and in order to continue with the test, a slab of calcium chloride accelerated concrete was inserted in its place.

The first test consisted in operating the wheel in a single lane on the inner half of the pavement for 20,000 passes; measurements were made of the amount of rutting at various stages of the test and apparently all seven sections in their naturally dried condition were stable. The results are given in Table III.

TABLE III

RESULTS OF STABILITY TEST ON FIRST CIRCULAR TRACK

	Screenings—only				Screenings with MC-1 Cut-back		
Section No.	1	2	3	4	8	7	6
Grading	Coarse	Med.	Fine	F+clay	Coarse	Med.	Fine
	Rutting—inches						
DRY TRACK							
After 4,800 passes	.02	.03	.09	.15	.03	.08	.01
" 10,000 passes	.03	.03	.11	.17	.03	.09	.02
" 20,000 passes	.03	.03	.12	.17	.05	.09	.03
WET TRACK							
After 15 passes	.95	.15	.00	.08	.71	.13	.32
" 47 passes	2.54	.52	.01	.27	2.49	.55	1.36
" 1,000 passes	..	..	.17	..	..	..	..

The most dangerous condition for stabilized base construction exists when there is excessive moisture present in the subgrade or on the road surface. Accordingly, a test was made on the seven sections under extremely wet subgrade conditions. To simulate this condition a trench 2 inches wide and 3 inches deep was cut next to the inner curb and entirely through all of the test sections. This trench was filled with water for a period of 7 days to permit absorption to take place both by the sub-base and by the stabilized mixes. The test wheel was shifted to the outer portion of the track and operated in a single lane until failure occurred. A clear idea of the test conditions for the dry and wet portions of the test are shown in Fig. 1. The depth of rutting which took place at different stages of the test is shown in the lower portion of Table III.

A study of the complete table will show that of the 7 sections capable of being tested, (Sec. 5 having

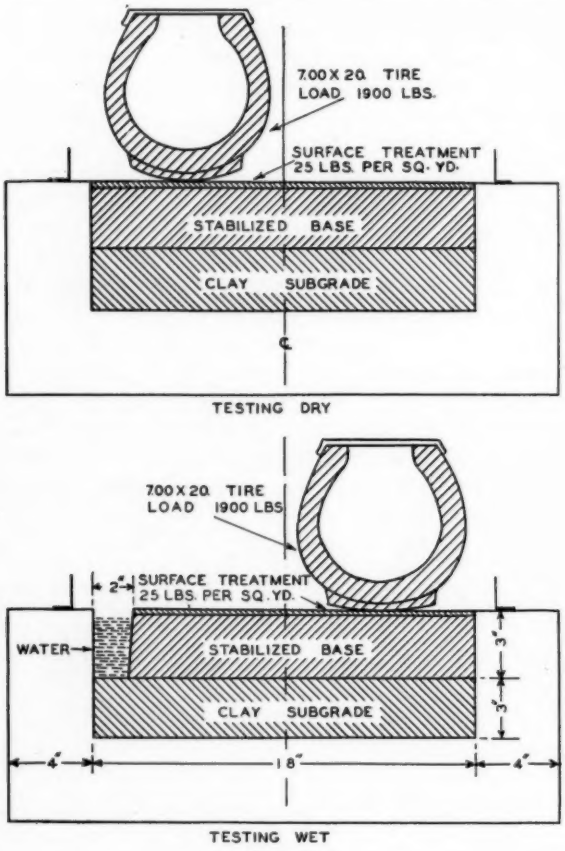


FIGURE 1.

failed during the compacting process) all of the sections were stable under the dry condition and there was no further movement after 4800 passes of the wheel up to the end of the test at 20,000 passes. On the other hand, when these same sections were tested in a wet condition as previously described, the two coarse graded sections, Nos. 1 and 8, failed under only 15 passes of the wheel. Sections 2, 6 and 7 failed at about 47 passes and all of the sections with the exception of No. 3 had completely failed at 100 passes of the wheel.

FIGURE 2.
Section 5 after 1,000 revolutions of loaded tire weaving over entire surface for final compacting prior to test.

FIGURE 3.
Section 1 after 15 passes of loaded wheel, track wet.

FIGURE 4.
Section 8 (with crack in foreground) and Section 1 after 15 passes of loaded wheel, track wet.

FIGURE 5.
Section 1, after 47 passes, track wet.

The amount of rutting, 0.17 inches after 1000 revolutions shown for section 3, was due primarily to carry over effects from the failed sections Nos. 2 and 4. Section 3 was the only stable section in this test. The accompanying photograps, Figs. 2 to 9 inclusive, show the various test sections after failure or at the end of the test.

Of course no definite conclusions can be drawn from a single test, but the indications from this first series are:

1. That stability under dry conditions is readily obtained, but a test made under these conditions is no indication of the probable behavior of the sections under wet condition.
2. High density seems to be desirable to prevent the infiltration of water and to create high stability under wet conditions.
3. That provided sufficient stone dust is available for high density, the addition of clay is not necessary and judging by a comparison of section 3 containing no clay with section 4 containing clay, it is obvious that the clay may actually be detrimental.
4. That MC-1 cut back asphalt exhibited undesirable properties for use in stabilized mixtures, probably due to the heavy nature of the volatile portion. It will be recalled that the MC-1 cutbacks are of the kerosene type of cut-back. More curing may have been beneficial.

Series II

In the first series only one type of cut-back asphalt was used and, accordingly, these tests were repeated using 18 to 25 viscosity tar, asphaltic emulsion such as used for soil stabilization and an RC-2 cut-back asphalt. The aggregates and gradations

FIGURE 6.
Section 2, after 47 passes, track wet.

FIGURE 7.
Section 3, after 47 passes, track wet.

FIGURE 8.
Section 4, after 47 passes, track wet.

FIGURE 9.
Section 8, after 47 revolutions with the track wet.

used in the several mixes were the same as in Series I. Data regarding the mixtures in Series II are given in Table IV.

TABLE IV

MATERIALS USED IN SECOND SERIES OF CIRCULAR TRACK TESTS

Section Number	Aggregate Grading	Bituminous Material		
		Type	Per cent Used	Per cent Water
1	Coarse	18-25 viscosity Tar	3.1	9.4
2	Medium	"	3.1	12.0
3	Fine	"	3.3	11.0
4	Fine + Clay	"	3.1	11.5
5	Coarse	Asphaltic Emulsion	3.1	8.3
6	Medium	"	3.1	10.0
7	Fine	"	3.1	12.0
8	Fine + Clay	"	3.1	12.0
9	Coarse	RC-2 Cut-back	3.1	9.2
10	Medium	"	3.1	11.4
11	Fine	"	3.1	12.1
12	Fine + Clay	"	3.1	12.7

The test sections in Series II were laid and cured and finally tested in the same manner as in Series I with the exception that in this series the sections were allowed to cure 2 weeks instead of 1 week before applying the bituminous surface treatment. It was learned from the first track that water was the principal cause of instability and, accordingly, samples for moisture content were taken at various stages of the test. The results of Series II are shown in Table V and the appearance of the various test sections at the end of the test are well illustrated in Figs. 10 to 20, inclusive.

Series II again proves conclusively that high stability is easily obtained when the mixtures are in a dry condition, but that when in a wet condition there is a wide range in stability. Apparently, gradation is the most important single factor in bringing about a stable condition under bad moisture conditions. The use of waterproofing materials such as tars, cut-backs or emulsions is not effective unless the mixtures are dense and have a sufficient amount of fine dust present.

A study of the bottom of Table V will show that Section 9 (coarse aggregate gradation with RC-2 cut-back) failed at only 270 passes under wet conditions. Sections 1, 5 and 6, two of them coarse and one of them of medium gradation, failed at 525 passages. While Sections 2, 7 and 10 failed at 5500 passes, sections 3 and 11 held up remarkably well and did not fail. The sections that did not fail in this test were Section 3, fine graded screenings containing 18 to 25 viscosity tar; Section 4, fine graded screenings plus clay containing 18 to 25 viscosity tar; Section 8, fine graded screenings plus clay containing asphaltic emulsion; Section 11, fine graded screenings containing RC-2 cut-back asphalt; and Section 12, fine graded screenings plus clay containing RC-2 cut-back asphalt.

It should be pointed out that the failures recorded here are failures of the stabilized mix or base and not failures of the clay sub-base. It is quite evident that there was very little gain in moisture content in the

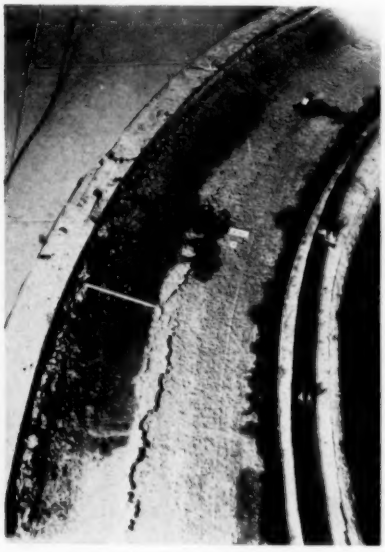


FIGURE 10.
Section 9, after 270 passes, track wet.

FIGURE 11.
Section 1, after 525 passes, track wet.

FIGURE 12.
Section 5, after 525 passes, track wet.

FIGURE 13.
Section 6, after 525 passes, track wet.

FIGURE 14.
Section 2, after 5,500 passes, track wet.

FIGURE 15.
Section 3, after 5,500 passes, track wet.

clay sub-base as seen in Table V. On the other hand, there was considerable gain in moisture content in many of the stabilized mixtures. If the voids in the mixtures are sufficiently great so as to permit the ready access of water, stability seems to be readily lost. Evidently failure occurred in the mixtures under the action of water and traffic by virtue of the internal pumping action produced by repeated deformations of the stabilized base course under traffic load. All of the mixtures in their dry condition still had a certain amount of moisture in them and yet they were stable. When this moisture content was increased they became unstable in many cases. It seems apparent that there is a certain optimum moisture content beyond which instability occurs. The coarse graded mixtures which fail rapidly were so saturated with moisture that pools of water formed in the holes from which the samples for

TABLE V.

SUMMARY OF SECOND CIRCULAR TRACK TEST ON STABILIZED SCREENINGS

Bitumen	18-25 Viscosity tar				Asphaltic Emulsion				RC-2 Cut-back			
Section No.	1	2	3	4	5	6	7	8	9	10	11	12
Grading	C	M	F	F+CLAY	C	M	F	F+CLAY	C	M	F	F+CLAY
TRACK DRY												
% Moisture—Clay Base	11.7	11.6	11.1	11.2	11.4	11.9	11.1	10.4	11.2	11.4	11.5	10.7
% Moisture—Mix	1.4	1.8	2.7	3.4	0.8	1.6	2.2	2.0	1.3	1.5	3.2	5.1
Rutting—inches												
5,000 passes	.09	.02	.02	.01	.03	.02	.02	.01	.04	.02	.00	.02
10,000 passes	.09	.02	.02	.01	.03	.01	.01	.01	.04	.02	.00	.02
20,000 passes	.13	.04	.03	.01	.03	.02	.02	.01	.08	.04	.02	.02
TRACK WET												
% Moisture—Clay Base	...	11.5	11.9	12.0	....	....	12.5	11.7	....	13.1	10.3	10.8
% Moisture—Mix	Sat.	2.3	3.2	3.8	Sat.	Sat.	4.1	2.9	Sat.	3.6	3.4	3.9
Rutting—inches												
270 passes	.18	.05	.02	.07	.19	.15	.07	.07	.51	.16	.02	.04
525 passes	.47	.05	.01	.06	.61	.52	.08	.06	....	.08 [a]	.01	.03
5,500 passes	...	.75	.01	.13	....	....	.79	.09	....	.36 [a]	.02	.03

Sat.—Saturated so that a moisture sample could not be taken.
[a] About half of the section that was showing failure at 270 revolutions was removed and the subsequent data gives the amount of failure in what appeared to be the stable portion of the section.

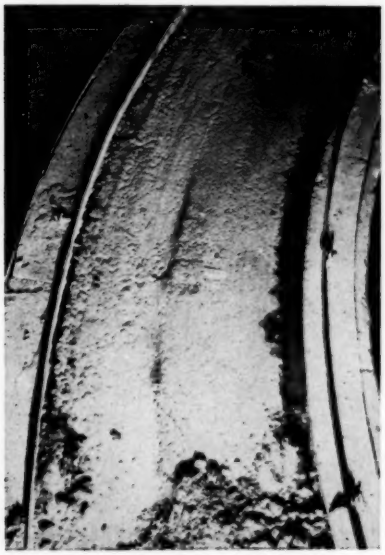


FIGURE 16.
Section 4, after 5,500 passes, track wet.

moisture were taken. It seems that the tar sections failed with a smaller increase in moisture content than in the case of the RC-2 sections, probably because the RC-2 asphalt retained its adhesiveness and the mixtures were more resilient. Of the dense graded mixtures all were stable except Section 7, an emulsion all screenings mixture. Evidently clay replacement for a portion of the stone dust was beneficial in the case of the emulsion mixture. It should be recalled, however, that where the emulsion was used, there was only about 2 per cent of asphalt present; a slightly higher percentage may have been beneficial. In conclusion, as the result of Series I and II, it seems that the best stability is obtained when the aggregate is graded to give high density and when there is sufficient bituminous material present to make for low absorption and to furnish some resiliency in the mix.

FIGURE 17.
Section 7, after 5,500 passes, track wet.

Additional tests will be conducted involving other variables and when completed, this investigation should give rather definite information regarding the proper use of screenings in stabilized base construction.

FIGURE 18.
Section 8, after 5,500 passes, track wet.

FIGURE 19.
Sections 10 and 11 after 5,500 passes, track wet.

FIGURE 20.
Section 12, after 5,500 passes, track wet.

Study and Standard of Quality of a Road Surface[1]

FROM THE VIEWPOINT OF (A) ITS SLIPPERINESS OR RUGGEDNESS, AND ITS RESISTANCE TO SKIDDING; (B) ITS PROPERTY OF REFLECTING OR ABSORBING LIGHT (UNDER ARTIFICIAL LIGHTING)

By R. H. BALDOCK
Chief Engineer, Oregon State Highway Commission, Principal Reporter

◆ **If the information so excellently summarized in the present article were applied more universally in highway construction, safer road surfaces would result. Highway safety is influenced to an important extent not only by methods of construction, but by materials also and, hence, this report is valuable not only to highway engineers, but likewise to materials producers.**

General Conclusions

1. To afford reasonable protection against the dangers of skidding, a road surface should have a static or side-skid friction coefficient of 0.4, or higher, at 40 miles per hour.

2. Pavements with a coarse sandpaper or slightly rough texture are more nonskid than pavements having a rough, knobby texture.

3. As the speed of the vehicle increases, particularly on wet surfaces, the coefficient of friction decreases.

4. The coefficient of friction of wet surfaces of the bituminous type increases with an increase of hardness of the asphalt or tar binder.

5. The coefficient of friction of wet bituminous surfaces varies through a wide range. The coefficients of the high-type, nonskid asphaltic pavements and bituminous macadam surfaces are consistently higher than the coefficients of other wet surfaces. However, unusually low coefficients are obtained on bituminous surfaces when such surfaces are covered by a skin of free asphalt.

6. The coefficients of wet portland cement concrete surfaces are from 15 to 50 per cent lower than those of high-type asphaltic surfaces under similar conditions of test.

7. The lower coefficients of friction of wet portland cement concrete surfaces, in comparison with present high-type bituminous macadam and asphaltic concrete surfaces under similar conditions, are unquestionably caused by the film of water retained on the surface of portland cement concrete pavements of current design. Tests indicate that the presence of the water film on the portland cement concrete surfaces is the probable cause of the reflection or glare from approaching headlights as evidenced on this type of pavement in comparison with the noticeable absence of glare afforded by the rough-textured surfaces of modern asphaltic concrete and bituminous macadam.

8. Changes in the design of portland cement concrete pavement surfaces to afford larger grooves to permit the rapid run-off of the water are necessary to increase skid resistance and to reduce the headlight glare of this type of pavement.

9. The larger of two tires of the same tread design will have the greater coefficient of friction. This substantiates the theory that the total frictional resistance of tires on road surfaces is equal to the true frictional resistance of the two materials plus the mechanical resistance which increases with the contact area of the tire.

10. On wet surfaces the squeegee action of the edges of new-tread tires provides a more intimate contact with the area of the road surface than is possible with smooth-tread tires and thus reduces the lubricating effect of the water.

11. Dry, light-colored pavements are from 2 to 4 times as luminous as dry, dark-colored pavements. No pavement has much luminosity when wet.

12. Smooth-textured pavements reflect more light than pavements having rough-textured surfaces.

13. Both smooth pavements and pavements having a fine, sandpaper texture are covered with a film of water, when wet, and this film is a very effective reflecting surface. Coarse-textured surfaces having pits or indentations of from ⅛ to ¼-inch in depth break up the water film and therefore reflect light in considerably lesser degree.

14. Reflective glare from wet surfaces is in the main a function of the texture of the surface and the least glare is given by those surfaces which are so deeply indented that water is not held by surface tension but drains off with sufficient rapidity to prevent the flooding of the entire surface and the formation of a water film to act as a mirror and reflect the lights of approaching vehicles.

[1] Report for the United States to the Eighth International Road Congress held at The Hague, June 19-July 2, 1938.

15. For a maximum of skid resistance and a minimum of glare, it is necessary to construct pavements having surface indentations or grooves deep enough to prevent the surface tension of water from holding a film of water on the surface. Moreover, the small particles of rock or sand should stand above and screen off the light from the water running in the indentations or grooves above described.

16. The surface texture of the pavement should be as fine as possible to accomplish the above objective inasmuch as a coarse, knobby texture reduces skid resistance.

17. Water film, when present on the surface of a pavement, acts not only as a lubricating medium between the tire and the pavement but also as a mirror to reflect light and cause dangerous glare.

A. Slipperiness or Roughness and Resistance to Skidding

Statistics collected and published by the Travelers Insurance Company of America indicate that about 1,500 persons are killed annually and that 30,000 persons are injured annually in the United States of America, by accidents reported as due to skidding on slippery road surfaces. While many of these accidents were in all probability caused by attempted driving at excessive speed, it must be borne in mind that, to the average motorist, skidding is a menace which causes uneasiness and discomfort even when no accident results. It is quite probable that many such accidents occurred on surfaces so slippery as to afford practically no friction between the tire and the pavement.

Any road surface used by motor vehicles should have sufficient roughness of surface texture to provide that friction between the tires of automotive vehicles and the road surface requisite for the safe starting, steering, and stopping of such vehicles under all reasonable conditions of operation. No road surface should be so slippery that skidding of the vehicle can occur when the vehicle is being operated in a reasonable and proper manner. Investigations have shown that the margin of safety for high-speed driving is small even on dry surfaces where high coefficients of friction are available.

The knowledge of the coefficient of kinetic friction between automobile tires and roadway surfaces now extant is due almost entirely to the work of Professor R. A. Moyer and his associates as reported in Bulletin 120 of the Iowa State College. This report will deal with the findings of Professor Moyer and his associates from numerous tests of the skid-resisting properties of various types of surfaces. It will also make use of the reports and observations contributed by various highway departments and other organizations and individuals.

Definitions

Coefficient of friction.—The coefficient of friction is the ratio between the force parallel to the road surface and the normal pressure of the tires upon the road when skidding is impending or actually taking place. If skidding is impending, the coefficient is called the coefficient of static friction, while if the movement is actually taking place the coefficient is called the coefficient of kinetic friction. Static friction will control skidding when a vehicle has just started and also the straight skidding in the direction of travel when the brakes are on the point of locking the wheels against rotation. Kinetic friction will control straight skidding in the direction of travel when the wheels are locked, and sidewise skidding in the direction normal to the line of travel with wheels either locked or rotating.

If a great force is necessary to cause skidding, the coefficient will be high, while if a slight force causes skidding the coefficient will be low. In other words, a pavement having a texture which enables the tires to grip the surface will offer great resistance to skidding and will have a high coefficient of friction. It therefore follows that highway surfaces are skid-resistant in the order of the ascending curve of the coefficient of friction.

Integrating dynamometer.—The integrating dynamometer is an instrument for measuring the force exerted by the vehicle when skidding straight ahead after the application of the brakes, or the amount of skid force exerted by the vehicle as it tends to skid sideways. The dynamometer is simple and rugged in construction, measures accurately to within 10 pounds forces ranging from 100 to 2,000 pounds, and its accuracy is not changed by the vibration set up in the test-trailer. This instrument was used in the tests hereinafter described.

Tests by Professor Moyer

Road tests to determine the slipperiness of various road surfaces under various surface conditions, as wet, dry, and snow- or ice-covered, were conducted by the Iowa Engineering Experiment Station in 1924 and again in 1927, under the direction of T. R. Agg. In 1932, the study was renewed and has been carried on continuously since that time under the direction of R. A. Moyer.

In the more recent work, all of the more important phases of skidding relating to highway safety were carefully investigated and analyzed. The resistance to skidding as measured by the coefficient of friction between the tires and the road surface was determined for 25 different types of surfaces. Tests were conducted with new tires of unworn tread design and with similar tires on which the tread had been worn smooth. They were conducted on wet and dry surfaces for both straight-ahead and sidewise skidding, at speeds ranging from 3 to 40 miles per hour, using a two-wheel trailer unit. Tests were made on pavements of brick, asphaltic concrete, portland cement concrete, on surfaces of penetration macadam using asphalt, tar, or road-oil binders, on surfaces treated with both tar and road oil, on gravel and cinder road surfaces, and on bridge floors surfaced with asphalt plank, steel plates, and hardwood plank. Tests were also made on mud-, snow-, and ice-covered surfaces both with and without tire chains.

On the basis of the results of braking-effort tests made with 2,134 cars and an analysis of the frictional requirements when braking, minimum safe-stopping distances were established.

Probably the most important phase of this investigation as far as this report is concerned is that which deals with the tests of the various road surfaces. It is now generally recognized that roads must be smooth-riding and free from large surface inequalities, yet skid-resistant to permit safe operation at the high speeds demanded today and the higher speeds which may be required by traffic in the future.

The Moyer tests indicated that skid-resistance can be provided in road surfaces of any type, and that the greater hazard, caused by snow, ice, and mud, can be materially reduced by maintenance. The tests indicated that practically all roads in the dry condition can provide the requisite friction with a liberal amount to spare for ordinary driving demands or even for emergency demands. Many surfaces in wet condition were found to be almost as safe as the same surfaces in dry condition, but the tests indicated that there is a large mileage of surfaces in the United States today which are dangerously slippery when wet.

In the earlier investigations of the skid-resistance of pavements, tests were conducted at low speeds at which the large uniform tractive forces required of the towing vehicle could be easily provided. In the more recent tests, the more variable effect of speeds ranging from 3 to 40 miles per hour was investigated. The results were startling because they indicated how slippery certain surfaces really are. On certain surfaces in wet condition, it was found that at 40 miles per hour the friction available is only ¼ to 1/5 as great as it is at 10 miles per hour. In fact, under certain conditions, these surfaces were found to be equally as slippery as snow- or ice-covered surfaces.

In theory, which was substantiated by the tests, the total frictional resistance to skidding is equal to the true frictional resistance between the two surfaces plus the resistance which results from a mechanical interlocking of the tire tread with the road surface. This mechanical resistance is brought about by the interlocking of minute particles of rubber with equally small projections in the road surface which tend to shear the rubber as the tire slides over the surface. In extreme cases skid marks are evidenced by the film of rubber left in the path of the skidding tire. The true frictional resistance is theoretically proportional to the normal load supported by the tire. The mechanical resistance, however, is dependent not only on the normal force or load on the tire, but depends also on the area of contact of the tire with road surface.

Surfaces which are smooth and which provide a large and intimate contact area for the tire, as indicated by tests, provide the greatest frictional resistance against skidding. Conversely, surfaces which have a rough knobby surface texture do not provide such an intimate contact, and therefore do not afford frictional resistances as great as those provided by the smooth surface with gritty finish.

On wet surfaces, the water serves as a lubricant if it cannot be squeezed or squeegeed from the surface as the tire rolls over it. At speeds above 25 to 30 miles per hour the tires fairly skim over the surface and it is far more difficult to remove the excess water and to overcome the lubricating effect. If the water is trapped between the tire and the road surface, skidding resistance drops off sharply. On wet surfaces, it is important to recognize that a large area of intimate contact is necessary to develop high frictional resistance; that small grooves should be provided in the road surfaces and in the tire to permit the excess water to escape; and that the aggregate on the surface should be hard and sharp, with many points of contact to grip the tire and prevent skidding. The tests revealed that highly polished or glazed surfaces are certain to be dangerous when wet. Examples of such types of surfaces are smooth steel plates, steel-troweled or highly polished concrete surfaces, and glazed-over asphalt surfaces.

The coefficients of friction of a considerable number of pavement surfaces when both wet and dry and at speeds of from 3 to 40 miles per hour were determined in the Moyer tests. Typical curves resulting from the tests are reproduced in figure 1; and in the following summary of the tests the average values from these curves are used. In figure 2, the results shown in figure 1 have been grouped so that those surfaces which give similar coefficients of friction under the conditions tested are shown by a single curve. Additional data relative to the effect of the condition of the tires are also shown in the lowest section of figure 1.

Tests on Various Types of Surface

1. *Portland cement concrete road surfaces.*—Portland cement concrete surfaces of reasonably uniform standard exist in greater mileage than any other type of high-class road surfacing used in the United States today. While the skidding resistance of wet portland cement concrete pavement was found to be not as high as that of certain bituminous surface types, the skidding properties of portland cement concrete were found to be the most consistent for both wet and dry surfaces of all the types considered. The tests indicated the desirability of grooving the surface or of finishing with a canvas belt so as to bring the sharp sand grains to the surface and remove or break up the coating of cement paste which is responsible for the slippery condition certain to develop on a portland cement concrete pavement finished with steel trowels.

The cement paste develops a hard surface finish which is polished smooth by the wearing action of traffic. Excessive manipulation, vibration, or finishing of concrete pavement surfaces draws an excess of cement paste to the surface and makes a slippery surface. Proper brooming or belting will provide a skid-resistant surface. The coefficient of friction of wet portland cement concrete surfaces ranges from 0.4 to 0.9 for straight skidding and from 0.5 to 0.8 for sidewise skidding; the coefficient of friction of dry, rough-textured portland cement concrete surfaces ranges from 0.8 to 1.0 for straight skidding and from 0.9 to 1.0 for sidewise skidding. The ranges given cover the coefficients for both new-tread and smooth tires.

2. *Bituminous road surfaces.*—The frictional resistance of bituminous road surfaces, as measured in the tests, varied more widely than the frictional resistance of any of the other surfaces tested. This general class of surfaces has been generally thought of by the traveling public as dangerously slippery when wet. While the results of the skidding tests on several bituminous surfaces substantiated this belief, the majority of the bituminous surfaces, when tested in the wet condition, gave a frictional resistance appreciably higher than that obtained on any other type of surface. The tests by Professor Moyer substantiate the conclusions of many highway engineers that it is possible to build bituminous surfaces that will be as free from the dangers of skidding as any road surfaces in common use today. The majority of bituminous surfaces built recently in the United States are nonskid in character.

An examination of the bituminous surfaces found in the tests to be slippery revealed that they were covered with an excess of bituminous material. The surfaces which offered high resistance to skidding were covered with sharp, hard sand, or with hard and finely crushed rock particles held in place by the bituminous cement. Such surfaces had a sandpaper-like finish. The coefficient of friction for wet bituminous surfaces varied through a wide range of values. The coefficients for wet, high-type asphaltic surfaces were consistently higher than those for the other wet surfaces tested. However, unusually low coefficients were obtained on some bituminous surfaces, particularly on wet penetration macadam built with a soft seal coat.

It is quite apparent that the coefficient of friction increased with an increase in the hardness of the asphalt or tar binder used in the bituminous surfaces. In this connection it is pertinent to refer to the recent tendency in the practice of State highway departments in the western portion of the United States toward the use of softer binders to overcome cracking of the surface. It is the reporter's opinion that, by and large, the cracking that develops is a function of weak foundations and poor drainage, and that these factors should be corrected before hastily deciding to use softer asphalts. The tests by Moyer indicate that it is a sound practice to construct seal coats with cut-back or emulsified asphalts, small amounts of which are sufficient for the thorough coating of the cover aggregate. The thin film of asphalt surrounding the stone particles firmly binds them together and the absence of an excess of asphalt below the cover stone insures a granular surface.

Competent observers are of the opinion that, when hot asphalt is used for sealing, a cover stone of ¾-inch diameter should be employed to prevent flushing of the excess asphalt to the surface. Professor

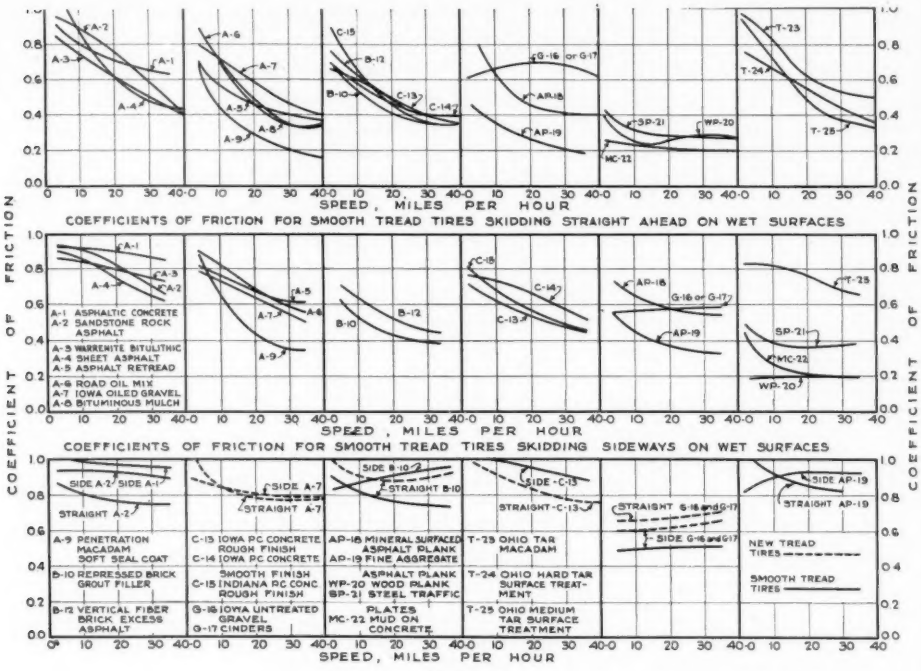

COEFFICIENTS OF FRICTION FOR SMOOTH TREAD TIRES SKIDDING STRAIGHT AHEAD ON WET SURFACES
COEFFICIENTS OF FRICTION FOR SMOOTH TREAD TIRES SKIDDING SIDEWAYS ON WET SURFACES
COEFFICIENT OF FRICTION
SPEED, MILES PER HOUR
A-1 ASPHALTIC CONCRETE
A-2 SANDSTONE ROCK ASPHALT
A-3 WARRENITE BITULITHIC
A-4 SHEET ASPHALT
A-5 ASPHALT RETREAD
A-6 ROAD OIL MIX
A-7 IOWA OILED GRAVEL
A-8 BITUMINOUS MULCH
A-9 PENETRATION MACADAM SOFT SEAL COAT
B-10 REPRESSED BRICK GROUT FILLER
B-12 VERTICAL FIBER BRICK EXCESS ASPHALT
C-13 IOWA PC CONCRETE ROUGH FINISH
C-14 IOWA PC CONCRETE SMOOTH FINISH
C-15 INDIANA PC CONC ROUGH FINISH
G-16 IOWA UNTREATED GRAVEL
G-17 CINDERS
AP-18 MINERAL SURFACED ASPHALT PLANK
AP-19 FINE AGGREGATE ASPHALT PLANK
WP-20 WOOD PLANK
SP-21 STEEL TRAFFIC PLATES
MC-22 MUD ON CONCRETE
T-23 OHIO TAR MACADAM
T-24 OHIO HARD TAR SURFACE TREATMENT
T-25 OHIO MEDIUM TAR SURFACE TREATMENT
NEW TREAD TIRES
SMOOTH TREAD TIRES

FIGURE 1.

Coefficients of Friction for New-Tread and Smooth-Tread Tires Skidding Straight Ahead and Sideways on Various Types of Road Surfaces.

Moyer's experiments have thoroughly demonstrated that a sandpaper surface which takes the wear of traffic directly on the mineral aggregate is the kind of surface it is desirable to construct. Contrary to general observation, sheet asphalt pavement, properly constructed with a sandpaper texture, is quite resistant to skidding. It is, of course, necessary to eliminate the usual surface dusting coat. Since a slight excess of asphalt will destroy the sandpaper finish and produce a glazed surface, it appears necessary in bituminous pavement construction of both the premixed and penetration types to use a hard aggregate and an asphalt with a high melting point. This is particularly true for the top or wearing course. The requisite proportions between the aggregate and asphalt binder should be controlled by careful inspection during construction.

Nonskid asphaltic surfaces can be built either in accordance with the principle of maximum density or by the use of the more open mixes. The latter are perhaps easier to construct and more certain in their results. The methods of building the more open-textured mixes and penetrations are described more thoroughly hereafter in the report on the Oregon practice.

The coefficient of friction of dry bituminous pavement ranges from 0.7 to 0.9 for straight skidding and from 0.8 to 1.0 for sidewise skidding; the coefficient of friction of wet bituminous pavement ranges from 0.2 to 1.0 for straight skidding and from 0.3 to 0.9 for sidewise skidding. Again these ranges cover the use of both new and worn tires.

3. *Brick pavements.*—Brick surfaces, free from excess filler, were found in the Moyer experiments to have skidding resistance slightly lower than that of portland cement concrete surfaces. Brick surfaces with excess filler that exudes or bleeds out of the joints, covering the greater part of the surface with asphalt, were found to be as slippery as bituminous surfaces with seal coats containing an excess of bituminous material. This would be expected since the cause of the slipperiness is the same in both cases —the excess bituminous material on the surface. Recent developments in the manufacture of paving brick and in brick pavement construction have greatly improved the skid-resistant properties of brick pavements. De-aired, vertical-fiber brick with lugs should provide a wear-resisting, gritty finish. Where there is any difficulty in obtaining the gritty finish, it is possible to face the brick with carborundum or emery grit during manufacture and thereby provide a wear-resisting and skid-resisting surface which should be the equal of any road surface now in general use.

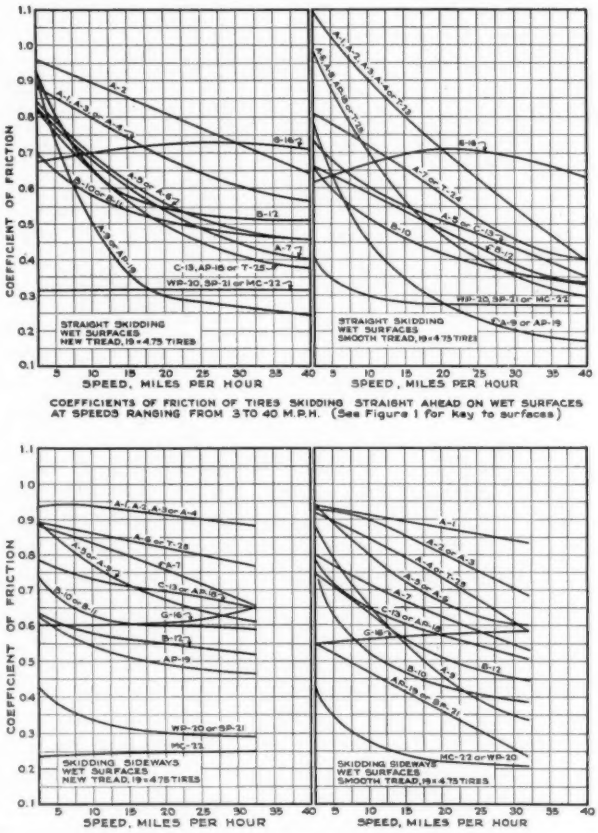
Bleeding of the joints has been practically eliminated by using a blended asphalt joint filler mixed with a mineral flour to provide a stable mix with a low coefficient of expansion. Before applying the joint filler, the brick surface may be sprayed with a separating agent consisting of a calcium chloride solution composed of 35 percent calcium chloride, 1 percent starch, and 64 percent water. By this method

any surplus overflow of asphalt from the joints during the filling process may be scraped and peeled off the surface after it has cooled and hardend, leaving a clean surface with flush-filled joints. Lime whitewash may also be used for this purpose. It is prepared by mixing finishing lime and water in the proportions of not less than 1½ sacks of lime to 50 gallons of water. The mixture should be prepared one day in advance of using. Methods for applying these separating agents are described in the report for the United States on brick pavements.

The coefficient of friction of dry brick pavements ranges from 0.7 to 1.0 for straight skidding and from 0.8 to 0.9 for sidewise skidding; the coefficient of friction of wet brick pavements ranges from 0.3 to 0.8 for straight skidding and from 0.4 to 0.7 for sidewise skidding; the ranges in each case covering the use of both new and smooth tires.

4. *Bridge floors.*—Wood plank, smooth steel traffic plates, and ordinary asphalt plank were found in the Moyer tests to be as slippery when wet as icy surfaces. It is particularly hazardous to use these materials on bridge floors. Skidding accidents under such circumstances are more hazardous because of the restricted roadway. Indeed, it is the reporter's opinion that they should not be used under any conditions as a highway surface unless they are provided with some type of nonskid finish. Wood planks may be covered with a bituminous treatment involving the use of cover stone of suitable size so as to give a gritty surface finish. Steel plates should have a stud or grid design providing sharp edges to grip the tires and prevent skidding. Likewise, the surfaces of ordinary asphalt plank should be covered with sharp gritty aggregate. In general, bridge floors are now covered either with portland cement concrete or high-type asphaltic concrete, both of which afford a satisfactory skid-resistant surface in wet weather.

5. *Sand, gravel, cinder, and macadam surfaces.*—Sand, gravel, cinder, and macadam surfaces all offer a higher resistance to skidding in either the wet or dry condition when the surface is firm and reasonably free from loose material. Loose aggregate, especially sand and gravel pebbles, acts in the same manner as ball bearings under the tires. It causes variations in the skidding resistance, making steering difficult, and in this way causes many accidents. Such surfaces also tend to become dusty in summer, materially reducing visibility, and thus, in another way, creating a hazard. The loose, dusty condition also increases the cost of transportation by causing increased fuel consumption, tire and car repair costs, and road maintenance costs. When there is considerable traffic, the cost of stabilizing the surfaces is unquestionably justified. In parts of the United States clay binder has been used with some success, but it has been clearly demonstrated that the presence of clay in a gravel or macadam surface lowers the chance of success of any subsequent treatment with oil or tar. In the opinion of the reporter, it is much more effective and cheaper in the long run to stabilize such surfaces with an asphalt or tar binder. This can be done either by the road-mix method or by the placing of a mat of oil, asphalt, or tar and screenings, as a wearing course.



COEFFICIENTS OF FRICTION OF TIRES SKIDDING STRAIGHT AHEAD ON WET SURFACES AT SPEEDS RANGING FROM 3 TO 40 M.P.H. (See Figure 1 for key to surfaces)

FIGURE 2.
Coefficients of Friction of Tires Skidding Straight Ahead and Sideways on Various Types of Road Surfaces.

6. *Maintenance.*—The results of the Moyer tests on mud-, snow-, and ice-covered surfaces, regardless of their construction, clearly indicated that these conditions are the most hazardous the motorist is likely to encounter. Ice and sleet were found to be particularly slippery, providing a frictional resistance of only about one-fifth of that provided by a dry concrete surface. The seriousness of the snow and ice

problem as related to skidding is indicated by the fact that about 80 percent of all skidding accidents in Iowa, for example, were found to occur in the 4 winter months.

The correction of this slippery condition is clearly a maintenance problem and demands prompt attention if it is to be effective. Ice forms on the road surface at a temperature close to the freezing temperature, and if sand and cinders are applied promptly at that time, the sand and cinders will be embedded in the ice, thus raising its frictional resistance to 3 or 4 times that which it can provide without such treatment. If the application of cinders or sand is postponed until lower temperatures prevail, the sand or cinders may not be embedded in the ice and the wind and traffic may whip them off the road. It is possible to apply the sand or cinders at lower temperatures if they are first heated or premixed with calcium chloride or rock salt. Such treatment causes the sand or cinders to become embedded in the ice the same as if placed at higher temperatures.

In certain States of the United States, notably Michigan, calcium chloride and sodium chloride have been applied directly on ice-covered surfaces. It has been found that such treatment, when applied to ice overlying portland cement concrete surfaces, causes serious damage to pavement and results in a form of scaling and a gradual disintegration of the concrete. For this reason it is suggested that the use of sodium or calcium chloride be avoided and that the sand or cinders be heated before application to ice-covered portland cement concrete surfaces.

Snow (particularly dry snow) has from two to three times the skid-resistance of ice. However, snow may so suddenly change to ice and is so difficult to distinguish from ice that the driver cannot be sure that a snowy surface is free from ice. It is therefore necessary to apply sand and cinders at intersections, on hills, and on curves as soon as the snow becomes packed. The practice of beginning snow removal coincidently with the beginning of the storm and of carrying on the snow removal operations continuously until the storm has ceased has become a standard procedure with State highway departments in the United States.

Mud on pavements constitutes a serious skidding menace. Where possible, the muddying of surfacings should be prevented by placing gravel coatings on shoulders and on muddy side roads, farm drives, or field entrances.

Roads that have glazed surfaces and are known to be slippery when wet should be covered with nonskid treatments of asphalt and mineral aggregate. Attempts have been made to apply heated sand or screenings on glazed bituminous surfaces, but the results have been more or less ineffectual. Usually the rolling operation cracks the stones, with the result that they are soon loosened by the traffic. Under particular conditions, as where soft asphalt with a low melting point has been used, it is sometimes possible to perform this work satisfactorily but, in general, the fact that the treatment can be given on only a few days of the year and a few hours in each day renders the method highly impractical. Likewise the correction of glazed surfaces by cutting back the excess asphalt with volatile solvents and applying gritty cover stone to blot up the excess binder has met with only mediocre success. The nonskid treatment of pavements by the placing of a mat of asphalt and stone chips has been found to be generally satisfactory, but the successful application of this treatment requires long experience and painstaking workmanship. The methods found most satisfactory in Oregon are described elsewhere in this report. The application of nonskid treatment on old concrete pavement is an even more difficult procedure because of the difficulty of successfully binding thin mats to concrete surfaces.

Observations by State Highway Departments

Wyoming.—The Wyoming Highway Department reports that practically all of its hard-surface roads are of bituminous type built at rather low cost according to a road-mix specification. The Wyoming experience indicates that when slow-curing oils are used there is danger of their softening during hot weather, allowing the aggregate to settle below the surface and leaving a film of asphaltic cement on the top of the wearing surface. The tendency in their present practice is toward the use of harder asphalt and sealing with a rapid-curing cut-back covered with sharp, clean sand.

Virginia.—The Virginia Department of Highways reports a method of making pavements nonskid that it has used recently on a section of U. S. Route No. 1 between Alexandria and Fredericksburg carrying a traffic of well over 6,000 vehicles daily. An original 18-foot concrete pavement had been widened on each side to provide for 3 lanes, and sheet asphalt had been laid over the entire surface. The sheet asphalt proved slippery during periods of heavy fog and rain, and to eliminate the hazardous condition, a nonskid bituminous surface treatment was applied on the grades.

The treatment consisted of an application of one-quarter gallon of cut-back asphalt heated to a temperature of 100° F. This binder was made from an asphalt having a penetration of 85-100 mixed with naphtha in the ratio of 2 parts asphalt to 1 part naphtha. Before the application of the cut-back binder, all cracks in the pavement were patched by hand. A slag covering was immediately applied at the rate of 20 to 22 pounds per square yard. Extreme care was used to effect a uniform distribution and no brooming was permitted. The slag was rolled lightly with a 5-ton roller, and traffic was kept off the road for a period of about 72 hours. The Virginia authorities report that excellent results were obtained on this section which has now been subject to traffic for about 4 months. They are of the opinion that the closing of the section to traffic for a time sufficient to allow the volatile materials in the asphalt binder to escape was one of the major causes of the successful results obtained.

Texas.—The State Highway Department of Texas reports that the quality of a road surface from the viewpoint of slipperiness or roughness and its resistance to skidding has been the subject of considerable study and research by that department for many years. The early concrete pavements built in the State were finished very smooth and they were found to be quite slippery when wet or damp. The condition has been corrected by the use of a belt on the freshly placed concrete at approximately the time it reaches initial set. It has been found that this finishing treatment raises the grains of sand in the mortar and creates light ridges in the surface which afforded a very satisfactory resistance to skidding. The skill of the workmen in the manipulation of the belt determines the type of surface secured; hence this practice has been subjected to careful control by the Texas Department for the past 7 years.

For the "nonskidding" or roughening of asphalt-surfaced roads the Texas department uses both a penetration and a premix type of treatment. In the penetration type treatment the nonskid surface is provided through the use of hard, angular, crushed stone or gravel placed uniformly over the surface as a wearing course. The amount of asphalt used is carefully controlled as are also the proportions and sizes of the lower course of rock. The entire course must be stable, and the amount of asphalt must be less than that which, penetrating upward through the surface course, would fill the voids between the rock and create a smooth surface. When the amount of asphalt is thus properly controlled, a surface affording satisfactory resistance to skidding is provided.

The premix asphaltic treatments are of two general classifications—hot mix and cold mix. In the cold-mix construction the most recent procedure is to place a light surface course of the open-mix type as the last course of the surface construction. This course is not more than ½ inch thick. The aggregate used is ⅜ inch in size and is very hard and sharp. The mix is so designed that the amount of mortar—that is, the portion of the mix below the 10-mesh screen—is not sufficient to fill the voids in the coarser aggregate and, in consequence, the ⅜-inch material is everywhere evident in the wearing course and provides a considerable resistance to skidding.

In the hot-mix construction, the surface course is placed by means of a mechanical finishing machine to a depth of from ⅜ inch to ½ inch. The aggregate is very hard, ⅜ inch maximum size, and the voids are only half-filled with mortar. The mix is placed at a temperature of 375° F. which creates a segregation due to the latent heat in the coarse aggregate. In normal asphaltic concrete construction, segregation is one of the things that is carefully avoided. However, in placing this nonskid surface it was accidentally found that by creating a segregation the type of surface desired was obtained.

The placing of the mix under the mechanical finishing machine in such a thin layer makes it necessary that it be sufficiently warm to work properly. It was found that when the temperature was raised slightly above the normal temperature—in other words to 375° F.—the manipulation of the surface by the finishing machine and the heat in the coarse rock caused the mortar to slip down into the bottom of the course by gravity which left the top open and the lower half of the large rock firmly embedded in the matrix. This provided the most satisfactory nonskid surface that has yet been laid in the State of Texas. It is obvious that the penetration of the asphalt must be low in order that the mix shall be stable. A 55-penetration asphalt has been used and it has been found that the high heat used in mixing and placing decreases this penetration normally to somewhere between 25 and 35.

Arizona.—The Arizona State Highway Department reports that in general its bituminous surfaces are constructed by the road-mix method, using slow-curing road oils and medium-curing cutback asphalt. These surfaces are covered either with a seal coat of 90 to 95 percent road oil and screenings ranging from ½ inch to those passing a 10-mesh sieve, or with 90

to 95 percent road oil premixed with the screenings of the same size. The department reports that it has, in every case, obtained a roughened surface with the requisite nonskid properties, but in some cases the roughened surface has later lost its roughness due to the softening of the surface and gradual embedding of the screenings until a smooth layer of asphalt appeared on the surface. The department is guarding against this condition by a more thorough study of the design of the mix.

Colorado.—The State Highway Department of Colorado reports that in its road-mix construction (bituminous surfaced roads), it guards against the use of too much asphalt. Surfaces are constructed with the minimum amount of asphalt required to supply the essential binder, the main course being followed by a seal coat containing a cover stone which provides a gritty surface resistant to skidding.

Kansas.—The Kansas Highway Commission calls attention to the prevalence of oil drippings along the quarter points of portland cement concrete pavements and to the resultant low resistance to sidewise skidding at those points. The department is attempting to devise ways and means to eliminate this oil streak as a maintenance process. Variations in the skidding characteristics of surfaces of bituminous macadam and other types of bituminous pavement have caused some concern in this State. To correct such conditions, use has been made of light applications of rapid-curing cutback covered with aggregate graded in size between the ¾-inch ring and the No. 8 square-mesh sieve. The Kansas engineers recommend the use of transition curves for highway alinement which will lessen the throw of the car caused by the sudden application of centrifugal force at the point of the curve. On slippery pavements, this throw frequently induces skidding.

Massachusetts.—The Massachusetts Department of Public Works stresses the banking of curves and the lengthening of curve radii as well as the design and construction of nonskid surfaces to prevent the hazard of motor car skidding. It recommends a surface free from depressions and bumps, and providing a maximum amount of angular particles of the mineral aggregate in contact with the tire and particles sufficiently large to resist the force causing the tendency to skid. The Massachusetts portland cement concrete surfaces have been constructed by the well-known method of brooming and afford sufficient angular contact with the tires.

The bituminous macadam surfaces of Massachusetts are known throughout the United States for their excellent quality. Great care is exercised to obtain the proper balance between the amount and kind of bituminous material and the size of the keystone. During the past few years, however, the Massachusetts department has developed a rather coarse, knobby surface texture without any cover of pea or chip stone. The large stones present a rough mosaic, the top of which is free of asphalt. Clean, properly graded broken stone of the resistance to wear and toughness required is used and this, when rolled, affords a firm, interlocking surfacing. Chip stones are used in quantities sufficient only to fill the voids below the top surfaces of the large stones.

The Massachusetts department has been of the opinion that this open, granular type is best from the viewpoint of skid prevention and that such pavements are as durable, if not more so, than the tighter, mat-covered pavements of former years. However, such roads cause an unpleasant rumble in a rapidly moving closed motor vehicle. The department recognizes this disadvantage and plans to return to the former method using a surface of finer texture. It is to be noted that the department's opinion in regard to the skid-resisting properties of the coarse, knobby type of surface does not coincide with the results of the research of Professor Moyer, which leads to the conclusion that all State departments should calibrate their types of pavement by means of equipment similar to that devised by Professor Moyer to the end that they may speak a common language and refer to definite values of the coefficients of straight-ahead and sidewise skidding. It would likewise be desirable if some standard device to measure the nonskid properties of various types of pavements could be universally employed.

Mississippi.—The Mississippi Highway Department reports that it is rolling bituminous-coated chips into both the Topeka and the sheet asphalt types of apshaltic concrete, thereby obtaining a very nonskid pavement surface.

Wisconsin.—The Wisconsin State Highway Commission has had some difficulty in maintaining bituminous surfaces, due to the flushing of the asphalt to the surface. It has remedied this condition by the application of a seal coat of additional asphalt and hard, sharp stone chips. It reports that it has found that ice melts more quickly on bituminous surfaces than on concrete, due presumably to the greater absorption of heat by the darker material. Some difficulty has been experienced in sanding ice covering portland cement concrete pavement because of injurious effects of the salts mixed with the sand and

cinders, which salts apparently have caused a later disintegration of the concrete surface.

Oregon.—As has been stated, it is necessary to build and maintain smooth-riding and skid-resisting surfaces. Rough pavements are the direct cause of skidding at high speed. The State Highway Commission of Oregon has devoted a great deal of time and study to devising ways and means for building smooth pavements of various types. It is axiomatic, however, that no matter how smooth pavements may be when originally constructed, they eventually become rough. Grade settlements, slight land movements, occasional weakness in foundations, and faults in drainage all tend to deform the pavement. Sooner or later, therefore, it becomes necessary to patch all pavements. Hence, it would seem to be highly desirable, if not necessary, to develop a technique and workmanship resulting in smooth patches. If patches are smooth, it should be possible to keep pavements in good condition, if not indefinitely, at least over long periods of time.

The Oregon department patches all pavements, regardless of type, with hot asphaltic concrete. The patches are nonskid in character and feathered to paper thinness at the edges. Dark asphaltic concrete patches on portland cement concrete pavements are objectionable to some extent, but they are few in number during the early life of the pavement and disfigure it less than might be supposed.

Portland cement concrete pavements are made smooth at the time of their construction by means of delayed finishing; that is, by delaying a part of the finishing until the shrinkage incident to the initial setting of the concrete has taken place, and by the further procedure of scraping down the high spots with heavy steel scrapers after the initial set has occurred. Very little scraping work is actually performed, however, as contractors, in order to avoid the expense of the scraping, perform the preceding finishing operations with the utmost care. Scraping is objectionable in that it removes the broom finish, leaving the scraped area smooth and less nonskid; but, as stated, the total area scraped is very small.

After extensive trial, the Oregon department has abandoned the mudjack as a means of pavement repair, having found that its use is only partially satisfactory in restoring the smoothness of the surface and that it results in much breakage of slabs into small sections which tend to rock and move under traffic. As the portland cement concrete pavements become progressively rougher, the asphaltic concrete patches increase in number until finally they constitute a complete resurfacing, with the concrete pavement serving as a base for an asphaltic concrete top.

Bituminous pavements constructed in Oregon are of two types, the plant-mix type and the penetration type. All plant-mix construction is of high-type asphaltic concrete of which there are two general classes, the minimum-void or closed-type mixes, and the open mixes. It is the theory of the reporter that it is very difficult to maintain a permanently nonskid surface with the densely graded mixtures for the reason that there are practically no voids for the asphalt to occupy under the influence of heat and the constant pounding of traffic. There is, therefore, the danger of free asphalt exuding upon the surface. It is possible, but rather difficult, to avoid this by a rigid control of the proportions of the aggregate and the percentage of asphalt, using the minimum of asphalt requisite to keep the mixture sealed and to prevent raveling in cold or wet weather. Very good results have been obtained in Oregon by exercising this rigid control, and pavements 5 years of age have retained the nonskid features required for safe driving.

The seal coat is eliminated from this specification and ½-inch screenings coated with 2 percent asphalt cement are rolled into the surface mixture, while it is still warm, at the rate of approximately 5 pounds per square yard. The proportions of aggregate and asphalt binder illustrating this type of construction are as follows:

Aggregate:	*Per Cent*
Passing 1¼-inch screen	100
Passing 1¼-inch and retained on ¾-inch screen	16-24
Passing ¾-inch and retained on ¼-inch screen	24-36
Passing ¼-inch screen and retained on 10-mesh sieve	12-20
Passing 10-mesh and retained on 200-mesh sieve	20-28
Passing 200-mesh sieve	3-6
Asphalt, 50-60 penetration	4. 5-6. 5

The open-type mix has sufficient voids for any probable expansion of the asphalt. When properly constructed, no evidence of the flushing of the asphalt to the surface has been noted. This construction is used as a wearing course only, and is placed upon an impervious, closed mix as a base. The grading of the materials and the percentage of asphalt are as follows:

Aggregate:	*Per Cent*
Passing ¾-inch screen	100
Passing ¾-inch and retained on ¼-inch screen	45-55
Passing ¼-inch screen and retained on 10-mesh sieve	30-36
Passing 10-mesh and retained on 200-mesh sieve	8-14
Passing 200-mesh sieve	0-2
Cut-back asphalt (RC-4)	4-6

In closed mixes, an asphaltic cement of 50-60 penetration is employed. In open mix, a heavy-grade cut-

back asphalt known as RC-4 is used, in which asphalt of 80-120 penetration is cut back with a maximum of 15 percent of naphtha as determined by distillation at 680° F. All types of asphaltic concrete mixtures are laid with finishing machines. The dense mixtures are laid at a temperature of 325° F. and the open type mixtures at temperatures ranging from 175 to 250° F.

In the early practice of the Oregon State Highway Commission, some rather high-crowned asphaltic concrete pavements, 16 feet in width, were constructed. These pavements were covered with a heavy seal coat of asphaltic cement and sand and they became very slippery in wet weather. It therefore became necessary to eliminate this very definite hazard. The first treatments consisted of one application of asphaltic cement or tar followed by a covering of stone chips or pea gravel. The results were, on the whole, mediocre. The stone tended to whip off the high spots, producing a surface of varying texture. Certain areas were covered with stone chips or pea gravel, affording a nonskid texture, while other areas were entirely bare of screenings and therefore slippery. It was finally found necessary to plane off the excess of asphalt from the surface of the old pavement. The asphalt and fine mineral material had accumulated in bumps and in certain cases had formed rhythmic corrugations.

The planing machine consisted of a heavy trailer of long wheelbase, carrying adjustable chisel-like cutting edges, pulled by a 60-horsepower crawler-tread tractor. The chisels were kept sharp and not only cut off the asphalt-sand mastic, but also sheared through the stones in the underlying mix. Repeated trips with the planer not only removed the excess of asphalt but also produced a very smooth-riding surface. The removal of the excess of asphalt eliminated any chance of its being drawn up into the new wearing course. Upon the planed surface was constructed, by the penetration method, a wearing course approximately 1¼ inches in thickness. Stone of maximum 1¼-inch size was used. The asphalt content was held to the minimum and excellent results were obtained. Surfaces treated in this manner some 8 years ago are practically as skid-resistant as when first constructed.

Probably the most uniform nonskid texture pavement laid in the State of Oregon is the penetration macadam type. The base stone, of 2½-inch to 1¼-inch size, is penetrated by hot asphaltic cement and covered with stone ranging from 1¼ inches to ¾ inch in size. This stone is carefully leveled by long-wheelbase motor graders. After the second application of asphaltic cement, the bituminous macadam is keyed with ¾- to ½-inch stone. This is followed by the first seal coat using ½- to ¼-inch and ¼-inch minus cover stone. Traffic is turned onto the pavement 4 or 5 days before the application of the second seal coat, after which the surface is thoroughly swept and the second seal employing the same size of aggregate is placed. This method effectively seals the penetration macadam against the admission of moisture. Hot asphaltic cement of 120-150 penetration, heated to a temperature of 425° F., is used in all cases with the exception of the last seal coat. A water-soap solution, in the amount of 10 percent of the hot asphalt by volume, is added through separate openings in the spray nozzles. The temporary emulsion formed covers the stone thoroughly. Either cut-back asphalt or emulsified asphalt is used for the second seal coat.

The surface texture of this type of pavement is somewhat coarser than a sandpaper finish, the ½-inch stone and some of the ¼-inch stone being present in the surface. The voids in the base stone act as a reservoir to absorb excessive asphalt in hot weather with the result that this type of pavement seldom bleeds and remains remarkably uniform in texture throughout the years. Oregon has had about 10 years' experience with this type of surfacing. In all, 2 gallons per square yard of bituminous cement, including the cut-back or emulsion, are required. The total aggregate used amounts to 0.111 cubic yards per square yard. Each course of the pavement is thoroughly rolled with 10-ton, 3-wheeled rollers.

B. Property of Reflecting or Absorbing Light (Under Artificial Lighting)

In view of the fact that consideration is now being given to the artificial lighting of certain sections of rural highways in the United States to eliminate the hazards of night driving, information concerning the quality of road surfaces in respect to their ability to reflect or absorb light is important. Moreover, since the majority of rural highways will, in all probability, remain unlighted on account of the expense, it is of prime importance that those properties of road surfaces which minimize the glare of approaching headlights, particularly on rainy nights, shall be carefully studied.

The reporter has endeavored unsuccessfully to obtain through published articles data relating to visibility and glare in connection with the various types of pavement surface. Apparently few data of this

kind have been assembled in the United States up to the present time. Accordingly a series of experiments of limited scope was undertaken by G. S. Paxson, Bridge Engineer, and J. D. Everson, Designer, both of the Oregon State Highway Department. The character of the equipment and the time available prevented any exhaustive study, but the results obtained give at least qualitatively a comparison between the various pavement surfaces examined.

Description of Investigation

Investigations were made to determine the light-reflecting properties of various types of pavements under artificial lighting conditions and to measure the reflection or glare from approaching headlights under both wet and dry conditions. Investigations to determine light-reflecting properties under artificial lighting conditions were made on 7 different types of pavement as follows:

1. A new concrete pavement completed and cured but not yet opened to travel. This pavement is broom-finished. The grooves are between 1/16 and ⅛ inch in depth, running transversely to the pavement. Duplicate tests were made with the incident light across the grooves as would be the case in normal lighting and with the incident light parallel to the grooves simulating a pavement broom-finished parallel to the highway center line. These two conditions are referred to in the accompanying charts as "new concrete parallel with grooves" and "new concrete across grooves," respectively.

2. A concrete pavement that has been in use 18 years. This pavement was constructed with a smooth surface and has been considerably stained and discolored by oil during service. The pavement is called "old concrete" in the accompanying figures.

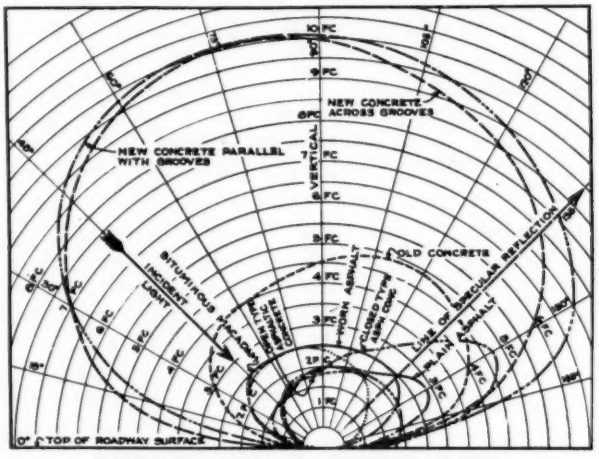
3. A section of old asphaltic concrete pavement quite rich in asphalt and showing no aggregate on the surface. This pavement is called "plain asphalt" in the accompanying figures.

4. An asphaltic concrete pavement that has been in service 15 years. The surface is quite smooth, but over at least 30 percent of the surface small aggregate particles protrude above the shiny asphalt finish. This pavement is called "worn asphalt" in the accompanying figures.

5. A modern asphaltic concrete wearing surface of the "closed type" as described in the first section of this report. This pavement is 3 years old and is called "closed-type asphaltic concrete" in the accompanying figures.

6. An asphaltic concrete pavement of the "open type" as described in the first section of this report. This pavement is 1 year old and is called "open-type asphaltic concrete" in the accompanying figures.

7. A section of bituminous macadam in service about 1 year. The surface of this pavement is composed of stone chips from ¾ to ½ inch in size which project above the body of the pavement about ⅛ inch. This pavement is called "bituminous macadam" in the accompanying figures.



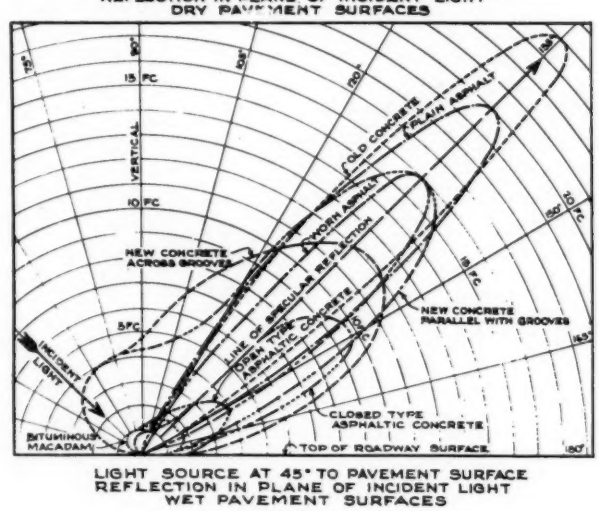


FIGURE 3.

Luminosity of Various Types of Road Surfaces When Dry and When Wet, for Light Source at 45° to Pavement Surface.

In fixed highway lighting the fixtures are suspended above the roadway surface at a considerable height, and the angle at which the light strikes the surface is controlled by the fixture. With a mount-

ing height of 30 feet and 200 feet between lights, the flattest angle will be about 17°, assuming that each light illuminates the surface halfway to the adjoining light. To simulate these conditions, measurements of the reflected light were made with an incident angle of 45° and with an incident angle of 17°. The light source was a 6-volt incandescent light mounted upon a tripod so that the angle between the light beam and the pavement surface could be accurately determined. The intensity of the light was controlled by a rheostat and voltmeter so that it was kept constant during the entire series of tests.

Reflection readings from the pavement surface, measuring the relative intensity of the light, were taken with a photometer attached to an arm which kept it at a constant distance from the point of reflection on the pavement surface. The intensity was measured in foot-candles. The angle which the axis of the photometer made with the pavement was measured on a dial attached to the frame supporting the photometer arm. The angle of incident light was kept constant and the intensity of the reflection was measured at each 15° around the semicircular arc. Readings were taken in the plane of the incident light.

Readings were first taken on the pavement surfaces when dry. The surfaces were then artificially wetted to simulate conditions during a rain, and the readings repeated.

Results of the Investigations

The results obtained with the light at an angle of 45° are shown in figure 3. Those above are for dry surfaces and those below are for the same surfaces when wet. It is interesting to note the regularity of the curves for dry pavement which show almost complete absence of specular reflection or glare except for the three smooth pavements investigated. These were the old concrete, worn asphalt, and plain asphalt. In addition, the closed-type asphaltic concrete, which is a relatively nonskid pavement, shows a decided bulge in the curve of readings taken for dry pavement. The curves for these pavements show a noticeable bulge in the direction of the line of specular reflection.

The difference between the luminosity of the dry portland cement concrete pavement and the dry asphaltic concrete pavement is quite noticeable. The new portland cement concrete pavements show about 4 times the luminosity of the asphaltic concrete pavements, while the old concrete pavements show about twice the luminosity. The rough and irregular bituminous macadam surface shows the property of being more highly luminous in the direction of the incident light than it is away from it.

These surfaces were then wetted and tested, other conditions remaining constant. The characteristics of the pavement have entirely changed and a great amount of specular reflection or glare is apparent. It will be noted that the new smooth pavements give from 4 to 10 times the intensity of glare produced by the rough-textured pavements.

The comparison of the two sets of curves shows that the luminosity of the pavements, except on the line of specular reflection, is one-half or less when wet than when dry; moreover, that in the case of plain asphalt or worn asphalt pavements there is practically no luminosity outside of the glare. This is supported by driving experience which discloses that the pavement appears very bright directly in the line of light sources but practically black at any other angle. It will be noted that while the luminosity of dry bituminous macadam pavement is only about one-fourth that of the new concrete, the glare, when wet, is less than one-sixth as great.

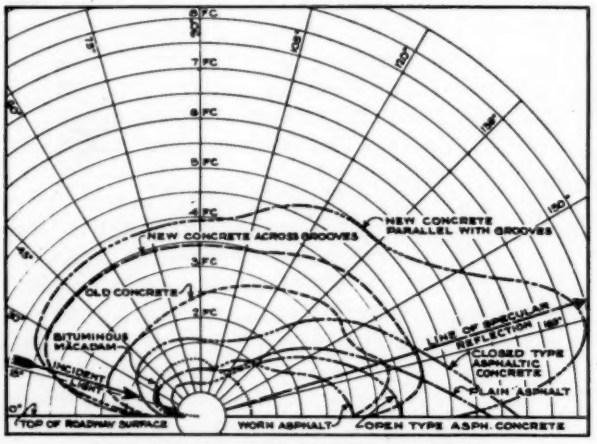
Figure 4 shows the reflection readings on dry and wet pavements with the angle of incident light at 17° with the pavement surface and with the readings taken in the plane of incident light. It should be noted that as the angle of incident light decreases, the glare increases with all types of pavement, wet or dry.

As in the preceding figures, the luminosity of the dry portland cement concrete pavement is from 2 to 4 times that of dry asphaltic concrete types. The specular reflection or glare from the plain asphalt and worn asphalt types, when dry, is from 2 to 3 times that of the luminosity in other directions. The reflection from concrete pavements, when wet, is 4 to 8 times the luminosity of these same pavements when dry. Bituminous macadam, when dry, shows practically no glare at all.

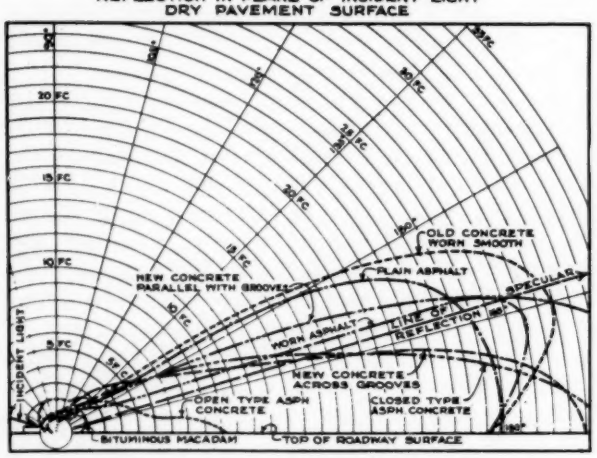
An examination of the lower part of figure 4 shows that none of the pavements has an appreciable luminosity when wet and that all but the bituminous macadam evidence some glare. An interesting point in this study is the decreased glare from portland cement concrete pavements when the light is across the grooves as compared with the same pavement when the light is parallel to the grooves.

From this study, it appears that under dry conditions, new, clean portland cement concrete pavements are more easily lighted than any of the darker asphaltic types. This is undoubtedly due to the light

color of the portland cement concrete pavement. The rough open-textured bituminous macadam surface produces the least glare when wet.



LIGHT SOURCE AT 17° TO PAVEMENT SURFACE
REFLECTION IN PLANE OF INCIDENT LIGHT
DRY PAVEMENT SURFACE



LIGHT SOURCE AT 17° TO PAVEMENT SURFACE
REFLECTION IN PLANE OF INCIDENT LIGHT
WET PAVEMENT SURFACE

Figure 4.
Luminosity of Various Types of Road Surfaces When Dry and When Wet, for Light Source at 17° to Pavement Surface.

It was noted during the experiment simulating rain that the smooth pavements were covered by a practically continuous sheet of water. Even the new concrete with its shallow broom marks became completely flooded. The high surface tension resulting from the small diameter of the grooves prevented the rapid run-off of the water. This suggests the formation of deeper, wider grooves in concrete pavement to afford quick run-off. The irregularities in the surface of bituminous macadam and new-type asphaltic concrete afford fissures or channels wide and deep enough to minimize the surface tension of the particles of water. Such surfaces are seldom entirely flooded and the stone chips projecting above the water surface break up the reflection and greatly reduce the glare. It is thus apparent that the glare is caused in the main by the reflection of the light from the sheet of water acting as a mirror. Means should be provided for constructing all types of pavement so as to afford rapid run-off of surface water. This is easily accomplished by the standard methods of building penetration macadam and the open-textured asphaltic concrete of the present day.

There is room for improvement in portland cement concrete pavements and it is suggested that consideration be given to the scratching of grooves approximately ¼ inch in depth, 1 inch apart, transversely across the pavement surface, while the concrete is still green.

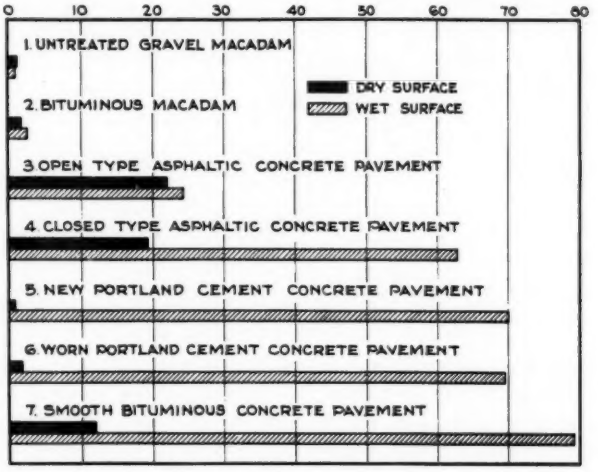


Figure 5.
Percentage of Intensity of Illumination Due to Surface Reflection for Various Types of Road Surfaces.

Investigation of Headlight Glare

In this part of the investigation, a 1937 model automobile with the headlights in the depressed or dim position was used as the light source. In this position the center of the light beam struck the pavement approximately 65 feet from the light. Readings of the intensity of the light at double this distance, or 130 feet, at the same elevation as the headlights, were taken with a photometer. A screen was then placed in the proper position so as to allow only the reflected light to reach the photometer. This eliminated the direct light from the headlights but meas-

(*Continued on page 29*)

Management's New Responsibilities[1]

By WILLIAM L. BATT
President, SKF Industries, Inc.
President, A.S.M.E., 1935-'36

◆ **Under the stress of current social and economic conditions management is constantly confronted with the necessity of assuming new responsibilities. In the following article one of America's leading industrialists gives us his conception of management's new job. We believe you will share our opinion that his observations are highly stimulating and thought provoking.**

IT IS becoming increasingly evident to management that it has other obligations than merely to earn dividends for stockholders. The head of one of America's largest organizations has stated it in these words:

"There rests upon them a far broader responsibility than the mere production of goods and services, or solely the interests of their stockholders. They must assume the important obligation, through proper policy, of attuning industry to a rapidly changing world, from social as well as economic standpoints." Stockholders might as well reconcile themselves, therefore, to the fact that management cannot always put their interests first in the obligation of business enterprise; and that the legitimate requirements of customers and employees have acquired a new significance which must be recognized if the business of today is to prosper.

This is not communism, nor treason to stockholders, nor even unbusinesslike, overgenerous altruism. It is, rather, the creed of what might be called the "new conservatives"—of those, that is to say, who want to preserve the profit principle, with a minimum of governmental interference, but who realize that if private enterprise is to survive, management must assume the tasks not only of providing purchasing power but of doing more and more toward simplifying the many problems of human relationships that exist in industry.

Popular dissatisfaction with things as they are takes many superficial forms, but at bottom today's difficulties are arising from the fact that more and more people want to be sure that they can enjoy more of the necessities and luxuries than they have so far been able to get with any degree of regularity. Knowing, as they do, that modern methods and machines have made an economy of plenty possible, potential consumers all the way down the economic scale have become clamorous for larger and less frequently interrupted shares.

The "have-nots," as they have been called, are not merely vociferous. They are powerful. Their present temper is to get what they feel they should have—legally, by their votes, if they can. If they fail in this it could happen that they would resort to some other means. Now, I do not want to put too much emphasis on the have-nots, or to have it appear that giving them what they ask is a panacea for all our troubles. It is well, however, for owners and managers of business to recognize this condition and to adopt policies and follow methods that will attempt to satisfy the proper requirements of consumers and workmen alike—remembering that all workmen are consumers and that the overwhelming majority of consumers are workmen.

* * * *

This is not merely throwing a sop to the enemy in the hope of buying peace. It is the adoption of a policy which the more farsighted men of business have recognized for some time to be the surest road to profits.

We are getting a better understanding of economics. It was once called "the dismal science." There is some doubt as to whether economics is, strictly speaking, a science. But certainly what it taught up to quite recently was dismal. Its laws—the one about supply and demand, for example—seem to have been largely based on the conviction that the sum total of wealth was more or less fixed, inflexible, inelastic. If that were true it followed that what was one man's gain must necessarily be another man's loss. With not enough to go around, one consumer's full stomach meant another's starvation. It was an equally inescapable conclusion that the only way a business man could expect to get a profit

[1] Condensed from a copyrighted article in *Dun's Review* for August, 1938, by permission of the publishers. Reprinted from the September, 1938, issue of *Mining and Metallurgy* through the courtesy of the American Institute of Mining and Metallurgical Engineers.

was by taking it away from someone else, mainly his customers and his employees because they were the easiest to handle.

Today economics is not so gloomy and depressing a subject, for it takes into account the humanities and is generally closer to the realities of life.

A few outstandingly successful business men have taught the academic economists that wealth is not rigid, that there is no trough of limited capacity from which each of us can get his share only at the expense of others, by dint of hoof and snout. These practical businessmen economists have proved that the biggest, continuing profits come not from piratical prowess, but from the creation of new wealth—which is production, or from rendering a worthwhile service—which is distribution. Compared to the profits from such constructive activities, the gains from victimizing customers or sweating labor are picayune.

Realization that a vast unsatisfied potential demand exists for nearly every kind of goods should come as a great relief to businessmen fed up with the struggle to take a comparatively small amount of the available business from a competitor. It is, as a rule, easier and less expensive to turn potential demand into effective demand than to fight competitive wars. All that is necessary is to provide purchasing power, which can be done by making consumers' dollars go farther, and by giving them more dollars.

One way to do that is by keeping prices as low as possible, bearing in mind that it is not the immediate large profit on a "fortunate" sale that is important, but rather the total profit year after year. I am not advocating price-cutting. That is not only likely to be disastrous to an industry, but basically unsound because it has for its purpose not the increasing of consumption, but the grabbing of business from a competitor. Whatever gain consumers realize from a price war is short-lived.

* * * *

Giving the consumer the best possible value in both price and quality is not merely constructive. It is a protective precaution made necessary by the increasing pressure being brought to bear upon government by consumers. As yet they are not as effectively organized as is labor, but they are on the way, and some day soon will be able to make their demands effective. As is usual with mass movements, when they get their way they may not be satisfied merely with products of adequate quality at a reasonable price. They may carry their demands beyond our present capacity to produce at low enough cost to give them what they ask for and still make a profit. It is up to the stockholders to permit management to adopt policies that will forestall such excesses.

* * * *

People must live, and they should have a reasonable certainty that so long as they do and are willing to work, they can have at least the necessities of life. We already have a small measure of unemployment relief and old-age benefits. If industry itself cannot give income the year around and security after a man's working days are over, popular opinion is likely to force the Government to enlarge this program.

In short, if business does not succeed in finding the means to give job security it will have to pay the bill indirectly through taxes. And that will always be the most expensive way.

I do not know specifically how these things should be worked out, but I know it is high time we do some straight thinking, with the probable result that we shall have to change many of our traditional ideas.

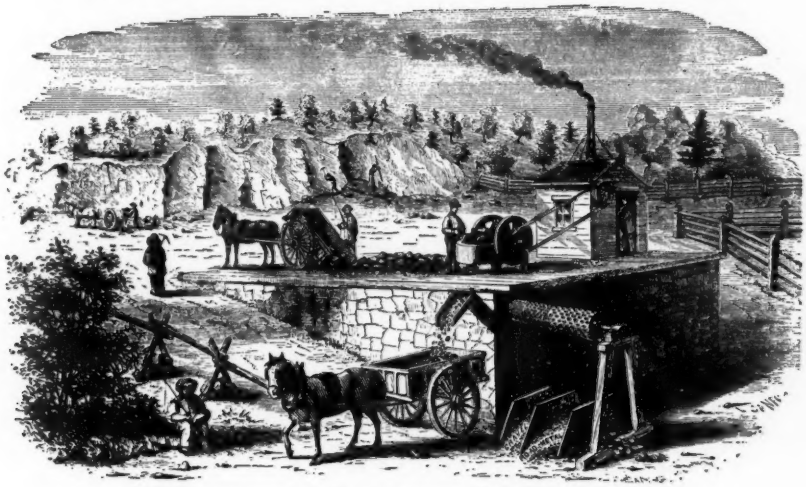
For example, even though all employees and many employers maintain that a workman is not a machine, most employees would be physically better off if they were treated like machines. This could be amplified in many ways and at great length. I want to make just one point. We buy our machines outright, except in a very few cases where they are leased, and after we have acquired them we must keep them, in good times and bad. No machine manufacturer would consider renting out a valuable machine on the basis that rent was to be paid for it only when it was in use, and that it need not be taken care of when a plant shutdown made it idle. Yet that is the way the custom of years has arranged things with our factory employees.

Speaking impersonally, it is not only inhuman, it is shortsighted; for when men are laid off without wages they cannot buy. Inevitably all of what industry pays in wages ultimately comes back through sales, despite the fact that the workman usually does not buy directly what he produces. Even though probably none of our Company's employees buys a roller bearing for his own use, many of them do buy them as ultimate consumers when they buy an automobile. They even, by great indirection, buy the bearings we make for factory shafting when they

(*Continued on page 29*)

Eli Whitney Blake and the World's First Stone-Crusher[1]

By RICHARD S. KIRBY and JOSEPH W. ROE



DEMONSTRATION OF BLAKE STONE CRUSHER, ABOUT 1875

EIGHTY years ago a New Haven inventor and manufacturer produced, in Westville (now part of New Haven), the first satisfactory machine for crushing stone.

From earliest days New Haven masons have been using local sandstone and the harder trap rock for foundations, chimneys and even entire houses. They did not use concrete, partly because they had no good cement, but mainly because the tough rock could not be broken into fragments except with hammers and at enormous expense. English laboring men, even women and children, of a century ago would sit all day beside enormous stone heaps and pound the chunks of stone into small fragments. But in this country, where wages have always been higher, such a method was never used with much success. American minds turned naturally to mechanical means. New Haven is proud that the problem of crushing stone by machinery was first solved successfully by one of her own citizens, Eli Whitney Blake.

Blake, born in Westboro, Mass., in 1795, and a graduate of Yale College, was a nephew and early business associate of Eli Whitney, another famous New Haven inventor and manufacturer. About a hundred years ago Blake, with two brothers established in the little hamlet of Westville, under the shadow of West Rock, a factory for making locks and general hardware. This firm, incidentally, was the first in the world to make the mortised or "set in" locks which we all use today.

In 1851 the wide road, Whalley Avenue, leading from Westville into New Haven was no better than a rough cart path. During parts of the year it must have been a difficult task even for teams of powerful horses to drag heavily loaded trucks through the deep sand ruts up the hill from the West River. Blake was appointed on a commission to see that the two-mile stretch between the West River and Broadway was "macadamized." There was no one in the city who could tell him how the work should be done, for such a road was quite new to America, almost a curiosity. In fact there were not a dozen miles of it in all New England. The name came from the Scotch engineer, John Loudon McAdam, who a few years before had introduced his type of road into England. Apparently the commission proceeded to surface Whalley Avenue with stone fragments, broken up by sledges and hand-hammers.

But Blake was not satisfied with the result. He puzzled for the next seven years over the problem of how to use steam or water power to break stone like trap rock (such as make up East and West Rock) into small and more or less cubical bits. He

[1] Reprinted through the courtesy of the New Haven Tercentenary Festival Committee.

not only puzzled over it, day and night, but he finally hit on the solution, a jaw crusher, one might almost call it a mammoth nut cracker. Next, practical engineer and mathematician that he was, he worked out on paper the proper proportions and details of each part before proceeding to build the machine. He found out by experiment just how much pressure it took to break trap rock. So carefully was his "stonebreaker," as he called it, designed, that the first machine served, with only slight modifications, as a pattern for the hundreds of all sizes that followed within the next few years. He secured a patent in 1858. His device has ever since been recognized the world over as the first successful stone crusher. He had in effect created a machine which would do the work of at least one hundred men.

This machine was, and is, essentially a pair of upright jaws, wide apart at the top and closer together at the bottom. One jaw is fixed, while the other advances toward and recedes from it, with a sort of vibratory motion. Power is applied through a flywheel. The large stones which are fed in at the top are gradually crushed smaller as they descend, and finally after they have been broken into small fragments, drop down into a bin.

Blake's invention deserves a high place because it was not simply an improvement or modification, as many inventions are, of something that already existed, instead it was a new creation. Within a few years the machine made its way into four major fields, highway construction, railroad track work, concrete foundations, and mining.

We have already mentioned the first of these. The Blake crusher may be said to have created a demand for better roads. One of the earliest Blake crushers to be used outside of New Haven served to crush Hudson River stone for the new Central Park driveways in New York City. Macadam road construction was greated stimulated as a result of the introduction of a machine which displaced so much gruelling human labor.

As railroad travel increased after the Civil War it became more and more desirable on many roads to lay ties in a bed of crushed stone or "ballast." This could now be readily supplied in quantity. Travelers by rail could thereafter, on stone-ballasted railroads, travel with considerably greater comfort, even dispense with the use of the common linen dusters.

Concrete, made from crushed stone, sand and cement was not common in America until long after the invention of the Blake crusher. It is now so widely used and for so many purposes that we almost take crushed stone for granted, as though it were a natural product. Blake helped to make our age the age of concrete.

Modern large-scale mining operations would not have been dreamed of had it not been for power crushers. Neither would Portland cement manufacture, for one of the first operations in a cement mill is the crushing of cement rock or limestone. Blake's invention thus reduced, for all of us, the cost of such materials as copper, lead, zinc, and cement. In 1861 one of Blake's first crushers found its way into the gold fields of California. There it broke up gold-quartz at such a rate as to astonish mine superintendents who had been employing hammer-wielding Chinese workmen. One machine in three hours crushed as much quartz as twenty-five men had been able to break up in a day, and not a nugget vanished surreptitiously.

All of these four major industries thus owe to Eli Whitney Blake a profound debt which New Haveners of this generation should be proud to acknowledge.

The first Blake crusher was set up, it would seem, on a little knoll just to the east of a spur of West Rock, close to what is now Springside Avenue. In fact a little crushing plant has been in operation there within this generation.

Blake was an active and useful citizen of New Haven. He lived for years in an eighteenth-century house at 155 Elm Street, now the home of the Graduates' Club. Here he died in 1886 at the ripe old age of 91.

Two Additional Plants Receive Honorable Mention in 1937 Safety Contest

SINCE reporting the winners of the National Crushed Stone Association Safety Contest for 1937 in the last issue of The Crushed Stone Journal, we have learned that two additional plants have been qualified by the United States Bureau of Mines as entitled to receive honorable mention for having completed the year 1937 with no lost-time accidents. The further recipients of this distinction are the Security plant of the North American Cement Corp. located at Security, Maryland, and the Knippa No. 4 trap rock quarry of the Southwest Stone Co. located at Knippa, Texas. The former operated 93,436 man-hours and the latter 56,064 man-hours.

Management's New Responsibilities

(*Continued from page 26*)

buy the cereal food or the shoes that are made in factories thus equipped.

Another basic idea that must be changed is that increased purchasing power in the forms of lower prices, increased yearly wages, and social security charges necessarily must reduce profits. On the whole, prices of industrial products, considering what the price will buy, have been going down for many years in spite of the fact that hours of work have been shortened and total yearly wages have been rising. And except during periods of business depression profits have not seriously suffered. This, of course, has been made possible by the increased production per man-hour resulting from improved machines and methods. Part of the savings, voluntarily or under pressure, have been divided between the consumer in lower prices and employees in higher wages; a fairly adequate remainder has gone to the stockholder as his profit. An excellent case can be made for the theory that one of the important causes of depressions is that too many producers have failed to distribute to others a large enough share of the savings and so have made it impossible for them to buy the increased production.

It is certain that improvements in production methods will continue to be made in the future. That should make it possible to reduce prices and increase wages and profits still more. If a fair division is made of the benefits few Americans will object to the owners getting an adequate share. Without that incentive private capital would have little encouragement to hazard the risks of business.

Another way in which we must change our thinking is to realize that business can continue to exist only if it is a useful servant of society. It has no vested rights. It operates under a charter from society. If it fails to serve society it will in time die from lack of nourishment. But before that happens, society may take the matter into its own hands and revoke the charter, which it has the moral right and the undoubted power to do. If society at present cannot do that legally it can pass laws which will make it legal.

* * * *

One of the best statements of this enlarged responsibility of management that I have seen is contributed by James F. Bell, chairman of General Mills, to a symposium on management to be conducted by the forthcoming International Management Congress. I can close this article with no more adequate summary than that given by Mr. Bell:

"Until recently management was synonymous with ownership; today it is synonymous with trusteeship. It holds in trust the investment of the stockholders, and, still more important, it holds in trust the jobs of the workers. In the performance of its trusteeship it is responsible to the public, for unless the public continuously accepts the results of its efforts, the stockholders cannot receive dividends or the workers receive wages. Without sound management capital is unproductive and labor idle, because neither of them can effectively serve the public unless management provides the connecting link."

Study and Standard of Quality of a Road Surface

(*Continued from page 24*)

ured the specular reflection or glare from the pavement surface.

The same pavement types previously described were tested, except that an untreated gravel macadam surface was added and the plain asphalt type was eliminated.

Figure 5 represents graphically the percentage of the total light reaching the photometer which was reflected light from each type of pavement tested both in a wet and a dry condition.

Attention is called to the fact that the wetting of the surface of the bituminous macadam and the open-type asphaltic concrete has little effect upon glare. This is borne out by driving experience over these types of surfacings. On the contrary, smooth and fine sandpaper-textured surfaces show a greatly increased glare when wet. Such surfaces, when wet, are covered with a film of water which becomes the reflecting surface, while the irregular surfaces, having pits or indentations ¼ inch or more in depth, break up the water film. It is thus apparent that the relative glare from wet surfaces is in the main a function of the texture of the surface, and the least glare is given by those surfaces which are so deeply indented that the water will drain off with sufficient rapidity to prevent the flooding of the entire surface and the formation of a water film which acts as a mirror in reflecting the lights of oncoming vehicles.

ACKNOWLEDGMENTS

The Principal Reporter acknowledges the very valuable data furnished him for the preparation of

this report. The contributors included R. A. Moyer, Associate Professor of Highway Engineering, Iowa State College; H. E. Phelps, Professor of Highway Engineering, State College of Washington; G. F. Schlesinger, Engineer-Director, National Paving Brick Association; Bernard E. Gray, Chief Highway Engineer, The Asphalt Institute; A. A. Anderson, Manager Highways and Municipal Bureau, Portland Cement Association; T. S. O'Connell, State Highway Engineer, Arizona State Highway Department; W. C. Ross, Assistant Construction Engineer, Arkansas State Highway Commission; J. E. Maloney, Assistant Engineer, Colorado State Highway Department; A. B. Nuss, State Highway Engineer, Kansas State Highway Commission; G. H. Delano, Chief Engineer, Massachusetts Department of Public Works; R. A. Harris, Chief Engineer, Mississippi State Highway Department; C. S. Mullen, Chief Engineer, Virginia Department of Highways; E. L. Roettiger, State Highway Engineer, State Highway Commission of Wisconsin; J. G. Smith, District Engineer, Wyoming State Highway Department; and G. S. Paxson and J. D. Everson of the Oregon State Highway Department.

The outstanding contribution of Professor R. A. Moyer of the Iowa State College forms the basis of the first section of this report. The Principal Reporter quoted freely from all the information furnished.

Use of Roads and Motors Creates Millions of Jobs Here and Abroad

AMONG the world's greatest producers of employment are activities linked with the manufacture and distribution of motor vehicles and automotive supplies, and highway transportation.

In this country, "highway transportation employment" reaches a total of more than 6,200,000 jobs, it is estimated by the National Highway Users Conference on the basis of government figures and other reliable data.

Now comes this report from Great Britain, as set forth by the Society of Motor Manufacturers and Traders:

"The motor industry contributes to national well-being by giving employment, in one form or another, to over 1,300,000 of whom 560,000 are employed in goods vehicle transport and 290,000 in the operation of public service vehicles, including taxicabs and hire cars. The oil and tire industries, coupled with general distribution and garage operation, employ over 150,000 persons. In addition, the industry, by the avenues of direct taxation and duties, provides a sum equal to one-eleventh of the total national revenues.

Great Britain has 1,842,333 passenger cars in operation, as compared with the United States total of 25,342,525. The United States has almost eight times as many trucks and buses as Great Britain, the figures being 4,362,695 and 576,395, respectively."

Pioneer Roadbuilder Passes Away

JAMES H. MACDONALD, "father of American good roads," died September 22, in New Haven, Conn., his home, at the age of 87. "Uncle Jim," as he was known to his thousands of friends and admirers throughout the United States, was one of the country's pioneer highway engineers and one of the original sponsors of the federal highway system.

The first highway commissioner of the State of Connecticut, he served in that capacity from 1897 to 1913. He was the first road builder in the state to plan highway construction with regard to a state system of trunk lines and state-aided town roads. He instituted a system of farm-to-market roads that became a model for such construction throughout the nation and made him popular throughout the country and in Europe as a speaker and authority on the subject.

Mr. MacDonald was a charter member and treasurer of the American Road Builders' Association, serving that organization as president for many years and becoming treasurer in 1918. The American Road Builders' Association, the Highway Research Board and the American Association of State Highway Officials jointly presented him with the George S. Bartlett Memorial Award in 1933 for his contributions to highway construction. In his later years he maintained an office of his own as a consultant in road building and its allied interests.

Funeral services were held Monday afternoon, September 26, in New Haven.

States Spend $779,856,000 on Highways in 1937

STATE highway departments expended $551,979,000 for highway construction and $227,877,000 for highway maintenance in 1937, according to State reports to the U. S. Bureau of Public Roads. Construction expenditure was $55,000,000 below the 1936 figure. Of the total State construction and maintenance expenditure of $779,856,000, $639,902,000 was

on primary rural State highways, $67,102,000 on secondary roads under State control, and $72,852,000 on urban extensions of State systems.

Total State highway expenditures—including payments on account of highway debt, State police, local roads and non-highway purposes—amounted to $1,166,706,000. There was a small increase in expenditures for non-highway purposes.

State road taxes and appropriations have all but disappeared as a source of State highway revenue.

Total State highway income in 1937 was $1,195,625,000. Income from State revenue sources was $835,867,000 of which $827,589,000 was derived from State imposts on motor vehicle users. Only about $705,000,000 was for use on State highways since $122,500,000 was earmarked for transfer for local roads and other uses. The Federal government contributed $262,762,000, funds transferred by local units amounted to $22,152,000, and income from bonds and notes was $65,009,000. Income from minor sources made up the remainder.

U. S. Funds To Build Toll Super-Highway

THE Federal Government is supplying all of the money to build a 162 mile toll super-highway between Harrisburg and Pittsburgh, Pennsylvania, costing $58,000,000. Of this huge sum, $26,000,000 will be a direct grant from the Public Works Administration and $32,000,000 a loan from the Reconstruction Finance Corporation.

This super-highway, the first of its kind undertaken in the United States, will be a four-lane road following the roadbed of the South Penn Railroad, begun as a rival to the Pennsylvania Railroad between Harrisburg and Pittsburgh many years ago, but never finished.

It is proposed to utilize nine partially excavated tunnels, originally intended as railroad tunnels. The nine tunnels will aggregate seven miles of highway. The turnpike is to be constructed with the most modern safety devices. There are to be no intersections throughout the length of the highway, entrance and exist points being provided with cloverleaf arrangements. Because of gentle curves and easy grades the highway will be free from the usual weather hazards which beset highways in the mountains during winter and rainy seasons.

Construction will be under the direction of the Pennsylvania Turnpike Commission.

Diversion Continues to be the Highway Users Public Enemy No. 1

THIRTEEN and one-half cents out of every dollar of State taxes paid by highway users in 1937 was assigned to uses other than highways, according to statistics from State authorities collected by the Bureau of Public Roads of the U. S. Department of Agriculture. This is two and one-half cents less than non-highway use in 1936. Highway user revenues distributed by the States amounted to $1,195,132,000.

These revenues included registration and license fees amounting to $410,401,000, gasoline taxes of $768,010,000, and special taxes on motor carriers of $16,721,000.

The revenues were distributed: $705,312,000 for State highway departments—a sum nearly equal to actual expenditures on primary State highways and urban extensions—$277,617,000 for local roads and streets, $8,261,000 for State park and forest roads, $42,529,000 for collection and administration, and $161,413,000 for education, relief and other non-highway purposes.

Highway user taxes have been justified on the grounds that they are needed for improvement of roads over which the vehicles must travel, according to the Bureau of Public Roads. The Bureau reports that there is no prospect that sufficient funds to correct all dangerous highway conditions can be provided in the immediate future and urges that all highway user revenues be devoted to highways.

American Road Builders' Association Proceedings Available

THE Proceedings of the Thirty-Fifth Annual Convention of the American Road Builders' Association held in Cleveland, Ohio, last January are now available upon request to the American Road Builders' Association in Washington.

The authoritative information contained in this publication makes it a valuable aid to highway engineers, contractors, manufacturers, distributors and other individuals interested in making our highways safer and more adequate. The publication should contain much information of interest and value to crushed stone producers.

MANUFACTURERS' DIVISION of the NATIONAL CRUSHED STONE ASSOCIATION

These associate members are morally and financially aiding the Association in its efforts to protect and advance the interests of the crushed stone industry. Please give them favorable consideration whenever possible.

Allis-Chalmers Mfg. Co.
Milwaukee, Wis.
Crushing, Screening, Washing, Grinding, Cement Machinery; Motors; Texrope Drives; Centrifugal Pumps; Tractors

American Bitumuls Co.
200 Bush St., San Francisco, Calif.
Bitumuls—Hot and cold mixes, Penetration and Stabilization

American Cyanamid & Chemical Corp.
Explosives Department
Koppers Building, Pittsburgh, Pa.
Explosives and Blasting Supplies

American Manganese Steel Division of the American Brake Shoe and Foundry Co.
389 E. 14th St., Chicago Heights, Ill.
Manganese Steel Castings, Renewable Lip Dippers

Atlas Powder Co.
Wilmington, Del.
Industrial Explosives and Blasting Supplies

Earle C. Bacon, Inc.
17 John St., New York City
Primary and Secondary Crushers, Rolls, Screens, Elevators, Conveyors—Complete Plants designed and equipped.

The Barrett Co.
40 Rector Street, New York City
Tarvia and Tarvia-lithic for Road Construction, Repair and Maintenance

Blaw-Knox Company
Blawnox, Pennsylvania
Trukmixers, Agitators, Shrink Mixers, Clamshell Buckets, Storage Bins, Batcher Plants, Measuring Batchers, Ready-Mixed Concrete Plants, Trukmixer Loading Plants

Brooks Equipment and Mfg. Co.
408-10 Davenport Road, Knoxville, Tenn.

C. G. Buchanan Crushing Machinery Division of the Birdsboro Steel Foundry and Machine Co.
90 West Street, New York City
Primary, Secondary and Finishing Crushers and Rolls

Bucyrus-Erie Co.
South Milwaukee, Wis.
Excavating, Drilling and Material Handling Equipment

Caterpillar Tractor Co.
Peoria, Illinois
Manufacturers of Diesel and Gasoline Track Type Tractors, Road Machinery, Diesel Power Units

Cross Engineering Co.
Carbondale, Pa.
Screen Plates and Sections, Perforated Plate, for Vibrating, Rotary and Shaking Screens

Dempster Brothers, Inc.
Box 3063, Knoxville, Tenn.
DempsteR DumpsteR

E. I. du Pont de Nemours & Co., Inc.
Wilmington, Del.
Explosives and Blasting Accessories

Easton Car and Construction Co.
Easton, Pa.
Quarry Cars, Truck Bodies and Trailers
Electric Heaters for Tar, Asphalt or Bitumen

Ensign-Bickford Co.
Simsbury, Conn.
Cordeau-Bickford Detonating Fuse and Safety Fuse

Frog, Switch & Mfg. Co.
Carlisle, Pa.
Manganese Steel Department—Manufacturers of "Indian Brand" Manganese Steel Castings for Frogs, Switches and Crossings, Jaw and Gyratory Crushers, Cement Mill, Mining Machinery, etc., Steam Shovel Parts

General Electric Co.
1 River Road, Schenectady, N. Y.
Electric Motors

Goodyear Tire & Rubber Co.
Akron, Ohio
Belting (Conveyor, Elevator, Transmission), Hose (Air, Water, Steam, Suction, Miscellaneous), Chute Lining (Rubber)

Gruendler Crusher and Pulverizer Co.
2915 N. Market St., St. Louis, Mo.
Rock and Gravel Crushing and Screening Plants, Jaw Crushers, Roll Crushers, Hammer Mills, Lime Pulverizers

Hardinge Co., Inc.
York, Pa.
Scrubbers, Pulverizers, Dryers

Harnischfeger Corp.
4400 West National Ave., Milwaukee, Wis.
A complete line of Power Excavating Equipment, Overhead Cranes, Hoists, Smootharc Welders, Welding Rod, Motors and Generators

Hayward Co.
50 Church Street, New York City
Orange Peel Buckets, Clam Shell Buckets, Drag Line Buckets, Electric Motor Buckets, Automatic Take-up Reels

Hendrick Mfg. Co.
Carbondale, Pa.
Perforated Metal Screens, Perforated Plates for Vibrating and Shaking Screens, Elevator Buckets, Hendrick Vibrating Screens

Hercules Powder Co.
Wilmington, Del.
Explosives and Blasting Supplies

Illinois Powder Mfg. Co.
1752 Pierce Bldg., St. Louis, Mo.
Gold Medal Explosives

The Jeffrey Mfg. Co.
Columbus, Ohio
Material Handling Machinery, Crushers, Pulverizers, Screens, Chains

Kennedy-Van Saun Mfg. and Eng. Corp.
2 Park Ave., New York City
Material Handling Machinery—Crushers, Pulverizers, Vibrating Screens

Kensington Steel Co.
505 Kensington Ave., Chicago, Ill.
Manganese Steel Castings, Dipper Teeth, Crawler Treads, Jaw Plates, Concaves and Hammers

Koehring Co.
3026 W. Concordia Ave., Milwaukee, Wis.
Mixers, Pavers, Shovels, Cranes, Draglines, Dumptors, Traildumps, Mud-Jacks

Koppel Division, Pressed Steel Car Co., Inc.
2515 Grant Bldg., Pittsburgh, Pa.
Air Dump Cars, Quarry Cars, and Portable Railway Materials

Lima Locomotive Works, Inc.
Shovel and Crane Division
1108 Lima Trust Bldg., Lima, Ohio
Power Shovels, Draglines and Cranes

Link-Belt Co.
300 West Pershing Road, Chicago, Ill.
Complete Stone Preparation Plants. Conveyors, Elevators, Screens, Washing Equipment, Speed-o-Matic Shovels—Cranes—Draglines and Power Transmission Equipment.

Ludlow-Saylor Wire Co.
Newstead Ave. & Wabash R. R., St. Louis, Mo.
Woven Wire Screens and Wire Cloth of Super-Loy, Manga-Loy and all commercial alloys and metals

Marion Steam Shovel Co.
Marion, Ohio
A Complete Line of Power Shovels, Draglines and Cranes

McLanahan and Stone Corp.
Hollidaysburg, Pennsylvania

The National Supply Co. of Delaware, Superior Engine Division,
1401 Sheridan Ave., Springfield, Ohio
Diesel engine equipment

Nordberg Mfg. Co.
Milwaukee. Wis.
Cone Crushers, Vibrating Screens, Classifiers, Diesel Engines, Steam Engines, Compressors, Mine Hoists, Underground Shovels, Track Maintenance Tools

Northern Blower Co.
6409 Barberton Ave., Cleveland, Ohio
Dust Collecting Systems, Fans—Exhaust and Blowers

Northwest Engineering Co.
28 E. Jackson Blvd., Chicago, Ill.

The Osgood Co.
Marion, Ohio
Shovels; Power: Gasoline, Diesel, Electric, Steam, Draglines, Clamshells, Cranes

Peoria Steel and Wire Co., Inc.
Box 52, Peoria, Ill.
"Paramount Spreaders"—for applying limestone for soil correction and improvement and powdered asphalt, crushed stone and like materials on streets and highways

Pioneer Engineering Works, Inc. formerly Pioneer Gravel Equipment Mfg. Co.
1515 Central Ave., N. E., Minneapolis, Minn.
Jaw Crushers, Roll Crushers, Horizontal Gradation Screens, Inclined Vibrating Screens, Revolving Screens, Belt Conveyors, Belt Conveyor Units, Quarry and Rock Plants

Pit and Quarry Publications
538 South Clark St., Chicago, Ill.
Pit and Quarry, Pit and Quarry Handbook, Pit and Quarry Directory

Robins Conveying Belt Co.
15 Park Row, New York City
Belt Conveyors, Bucket Elevators, Gyrex and Vibrex Screens, Feeders, Design and Construction of Complete Plants

Rock Products
205 West Wacker Drive, Chicago, Ill.

Ross Screen and Feeder Co.
19 Rector St., New York City
Ross Patent Chain Feeders for Feed Control of All Sizes Rock, Ores, Gravel, etc.

Screen Equipment Co.
9 Lafayette Ave., Buffalo, N. Y.
Vibrating Screens

Simplicity Engineering Co.
Durand, Mich.
Simplicity Gyrating Screen, Simplicity D'centegrator, Simplicity D'watering Wheel

Taylor-Wharton Iron & Steel Co.
High Bridge, N. J.
Manganese and other Special Alloy Steel Castings

The Texas Co.
135 E. 42nd St., New York City

The Thew Shovel Co.
Lorain, Ohio
Power Shovels, Cranes, Crawler Cranes, Locomotive Cranes, Draglines. Diesel Electric, Gasoline. 3/8 to 2-1/2 cu. yd. capacities

The Traylor Engineering & Mfg. Co.
Allentown, Pa.
Stone Crushing, Gravel, Lime and Cement Machinery

Troco Lubricating Co., Inc.
2728-34 N. Salmon St., Philadelphia, Pa.
Troco Crusher Grease, Troco Safety Lubricants

Trojan Powder Co.
17 N. 7th St., Allentown, Pa.
Explosives and Blasting Supplies

The W. S. Tyler Co.
3615 Superior Ave., N. E., Cleveland, Ohio
Wire Screens, Screening Machinery, Scrubbers. Testing Sieves and Dryers

Warren Brothers Roads Co.
P. O. Box 1869, Boston, Mass. or
38 Memorial Drive, Cambridge, Mass.
Complete plants and separate plant units for bituminizing all types of stone, sand and gravel aggregate paving mixtures

Westinghouse Electric and Mfg. Co.
East Pittsburgh, Pa.
Transformers, Switching Equipment, Locomotives, AC and DC Motors and Control, MG Sets, Welding Equipment, Gear Motors